Why Care About MSS Data? We Owe It To William Pecora

Landsat Missions: ***Imaging the Earth Since 1972***

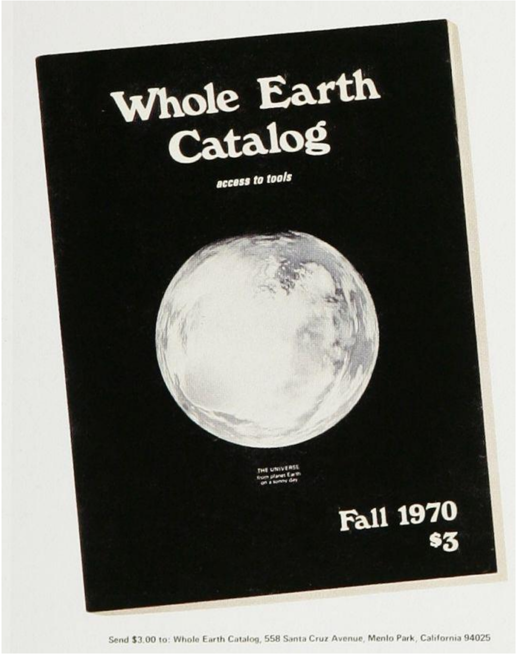
In the mid-1960s, stimulated by U.S. successes in planetary exploration using unmanned remote sensing satellites, the DOI, NASA, and the Dept. of Ag. embarked on an ambitious effort to develop and launch the first civilian Earth observation satellite (http://landsat.usgs.gov/about_mission_history.php)

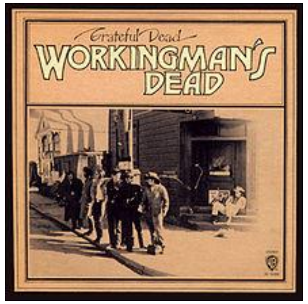
Warren B. Cohen, USDA Forest Service

Landsat Science Team Meeting, Virginia Tech, Blacksburg, 12-14 January 2016

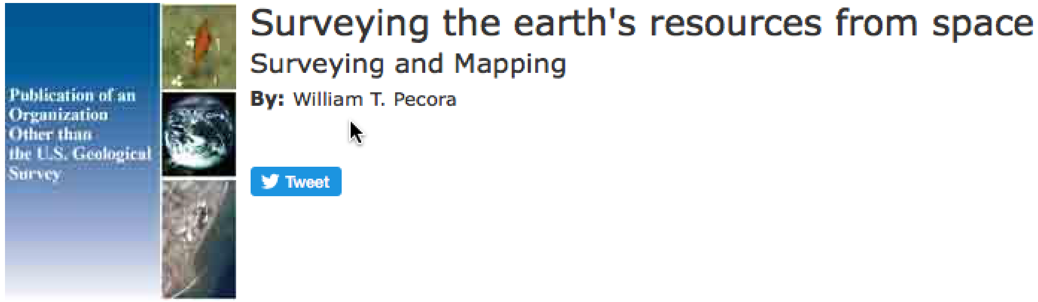
Abbreviated History: Birth of the US Environmental Movement

- Earth Day, April 22, 1970…widely believed to herald the birth of the modern environmental movement
- Mass consciousness about air and water pollution and accelerated losses of primary forest and biodiversity around the world were on the rise
- Same year the US EPA was created and with it the Clean Air Act; followed by the Clean Water and Endangered Species Acts a few years later



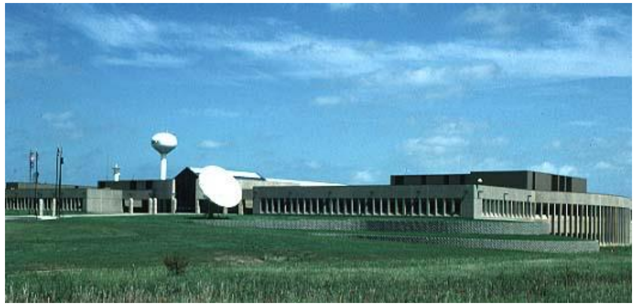


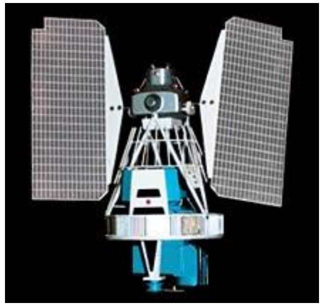
But the Environmental Movement Doesn’t Begin There…One Thread…..



- Approximately 1966, William T. Pecora, Director, USGS, had a dream … to learn more about the dynamics of our own planet as influenced by natural events and human activities (Williams et al. 2006. *Landsat: Yesterday, Today, and Tomorrow*, PE&RS)
- Pecora envisioned a series of land-observing satellites serving the Earth science community…His persistence prevailed upon a reluctant bureaucracy… (Goward et al. 2006. *Historical Record of Landsat Global Coverage*, PE&RS)
- In 1966, Secretary Udall announced “Project EROS” (Earth Resources Observation Satellite), stating “…the time is right…it is now urgent to apply space technology towards the solution of many pressing natural resource problems being compounded by population and industrial growth” (Loveland and Dwyer. 2012. *Landsat: Building a Strong Future*, RSE)

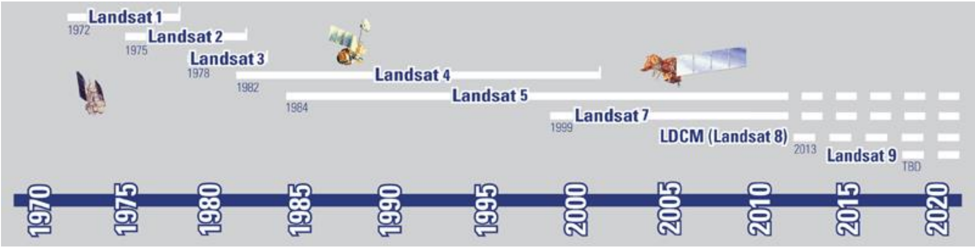
Landsat In Support of the Environmental Movement





- In 1970 NASA was given the green light to develop the first satellite-based Earth Observing System for land applications, and two year later, 23 July 1972 the first Landsat was launched
- Return Beam Vidicon – a television-like camera – was supposed to be the primary instrument, but the highly experimental Multispectral Scanner (MSS) digital sensor quickly became the more important of the two, and modern digital remote sensing was ushered into service to support the nascent environmental movement
- In 1973, USGS constructed a facility outside of Sioux Falls, South Dakota dedicated to receiving, processing, distributing, and archiving Landsat MSS and RBV imagery

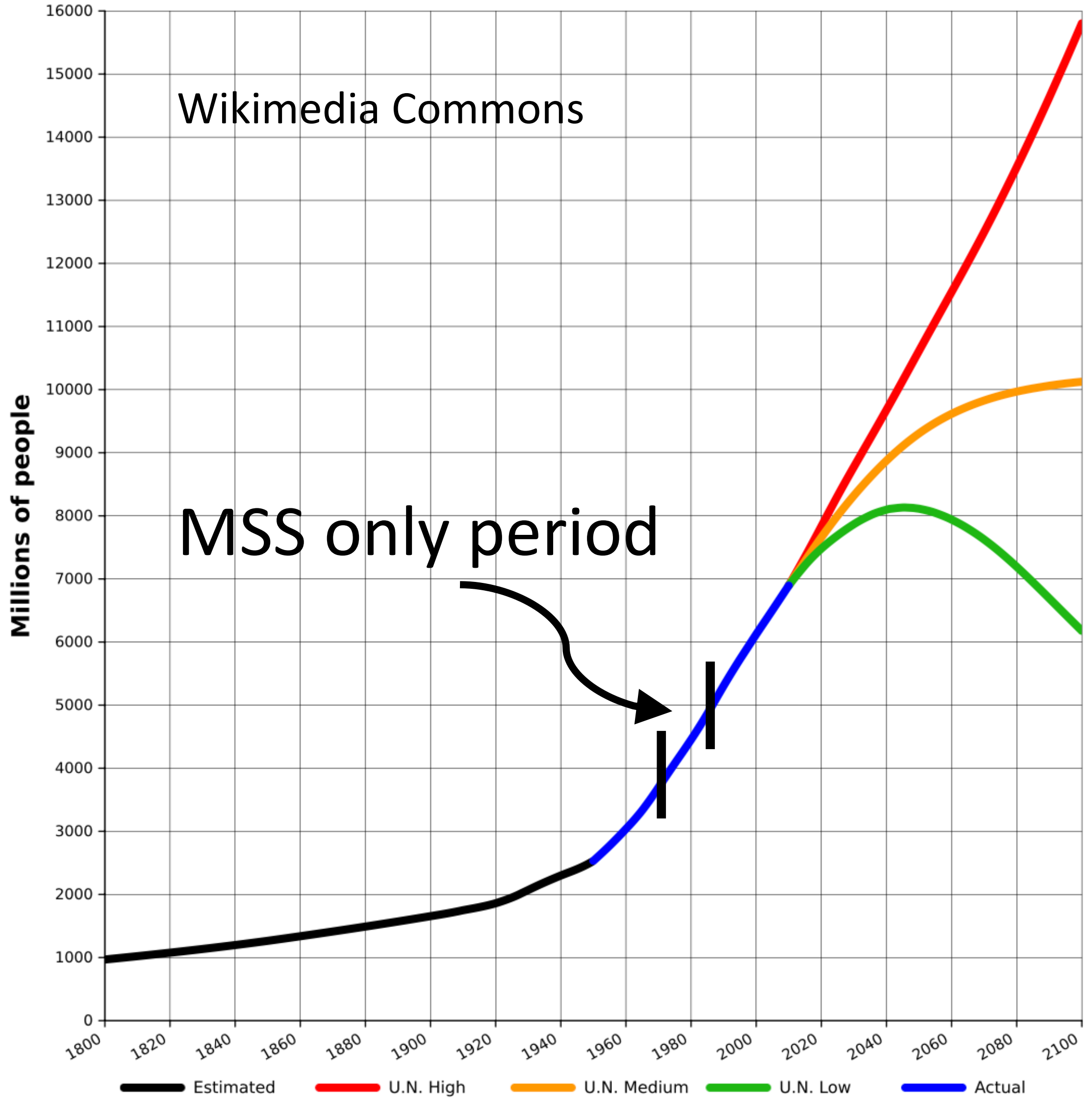
Landsat In Support of the Environmental Movement



- MSS data remained the only viable option for civilian space-based, global coverage of the land at a spatial resolution commensurate with human-caused change (~60 m) for over 10 years, thanks to the subsequent successful launches of Landsats 2 and 3
- In 1982, the next generation Landsat 4 sensor – Thematic Mapper – was launched, but technical difficulties meant it wasn't until 1984, when Landsat 5 was launched, that MSS lost its prominence as the most important space-based land remote sensing tool
- With improvements embodied in Landsat 7 ETM+ and OLI on Landsat 8, and the new developments wrapping TM to OLI data in nice time series packages, the value of MSS data may be lost if not rescued soon

Why Rescue MSS Before It Becomes An Artifact of History?

- 1972 - 1984 was a period of rapid population growth and commensurate environmental change
- Human population increased from ~3.87 billion to 4.77 billion (23% increase), already well into the modern, steady rise in global population that reached ~7.18 billion by 2014



Does MSS Data Remain Relevant to Science?

- Google Scholar Search (January 2016)
  - 36,700 articles mention MSS data
  - 10,700 since 2010 (29%)
  - 49 publications since 2010 with MSS in title (wide range out outlets)
    - Accuracy assessment
    - Calibration
    - Cloud masking
    - Geometric correction
    - Computing requirements
    - Analysis

About 36,700 results (**0.03** sec)

Summary of current radiometric calibration coefficients for **Landsat MSS**, TM, ETM+, and EO-1 ALI sensors
G Chander, BL Markham, DL Helder - Remote sensing of environment, 2009 - Elsevier
This paper provides a summary of the current equations and rescaling factors for converting calibrated Digital Numbers (DNs) to absolute units of at-sensor spectral radiance, Top-Of-Atmosphere (TOA) reflectance, and at-sensor brightness temperature. It tabulates the ...
Cited by 1168 Related articles All 6 versions Cite Save

[CITATION] **Landsat MSS** and TM post-calibration dynamic ranges, exoatmospheric reflectances and at-satellite temperatures
BL Markham, JL Barker - EOSAT **Landsat** technical notes, 1986
Cited by 857 Related articles Cite Save

[CITATION] Measuring'forage production' of grazing units from **Landsat MSS** data
DW Deering, JW Rouse - International Symposium on Remote Sensing of …, 1975
Cited by 256 Related articles Cite Save

[PDF] Detecting forest canopy change due to insect activity using **Landsat MSS**
RF NELSON - Photogrammetric Engineering and Remote …, 1983 - researchgate.net
ABSTRACT: Multitemporal **Landsat** multispectral scanner datu were anulyzed to test various computer-aided analysis techniques for detecting significant forest canopy alterution. Three data trcinsforn~ utions-differencing ratioing, and a vegetative index difference-were tested ...
Cited by 299 Related articles All 6 versions Cite Save More

[PDF] Statistical method for selecting **Landsat MSS** ratios
PS Chavez, GL Berlin, LB Sowers - Journal of applied …, 1982 - researchgate.net
Abstract To overcome certain problems associated with the visual selection of **Land sat MSS** ratios for color-combining, the authors devised a quantitative technique that ranks the 20 possible three-ratio combinations based upon their informational content. By use of ...
Cited by 283 Related articles All 2 versions Cite Save

Estimating changes in vegetation cover over time in arid rangelands using **Landsat MSS** data
G Pickup, VH Chewings, DJ Nelson - Remote Sensing of Environment, 1993 - Elsevier
Abstract Changes in vegetation cover over time in arid rangelands can be used to monitor land condition and to identify processes of land degradation. This article describes how a cover index can be derived from **Landsat MSS** data and how the index can be ...
Cited by 198 Related articles All 9 versions Cite Save

Destriping **Landsat MSS** images by histogram modification
BKP Horn, RJ Woodham - Computer Graphics and Image Processing, 1979 - Elsevier
Abstract Before images obtained by multisensor cameras can be used in image analysis, corrections must be introduced for the differences in the gain or transfer functions of the sensors. Methods are here presented for obtaining the required information directly from ...
Cited by 185 Related articles All 6 versions Cite Save

Analysis (since 2010)

- Regions
  - Africa
  - Australia
  - Brazil (Amazon, Mian Gerais)
  - Chile
  - China
  - England
  - Ethiopia
  - Germany
  - Greece
  - Iran
  - Iraq
  - Japan
  - Mexico
  - Qatar
  - Panama
  - Philippines
  - Syria
  - US (Alabama, Florida, Mississippi, Western forests)
  - Vietnam

- Earth feature
  - Coastal change
  - Deforestation
  - Environmental monitoring
  - Forest insect disturbance
  - Forest succession
  - Geomorphology
  - Lake extent changes
  - Land cover change
  - Land cover classification
  - Landslide detection
  - Oil spill effect
  - Primary forest mapping
  - Seagrass distribution
  - Sea surface
  - Soil salinity
  - Urban growth
  - Volcanology
  - Water quality

Why Am I a Strong Proponent of MSS?

- Forest disturbance (1972-1991) effects on landscape-level carbon stores (Cohen et al. 1996, *BioScience*)
- Spin-offs for forest succession
  - Yang et al. 2005. Can. J. For. Res.
  - Schroeder et al. 2007. FE&M; 2008 JARS.
  - Masek et al. NAFD

Two Decades of Carbon Flux from Forests of the Pacific Northwest

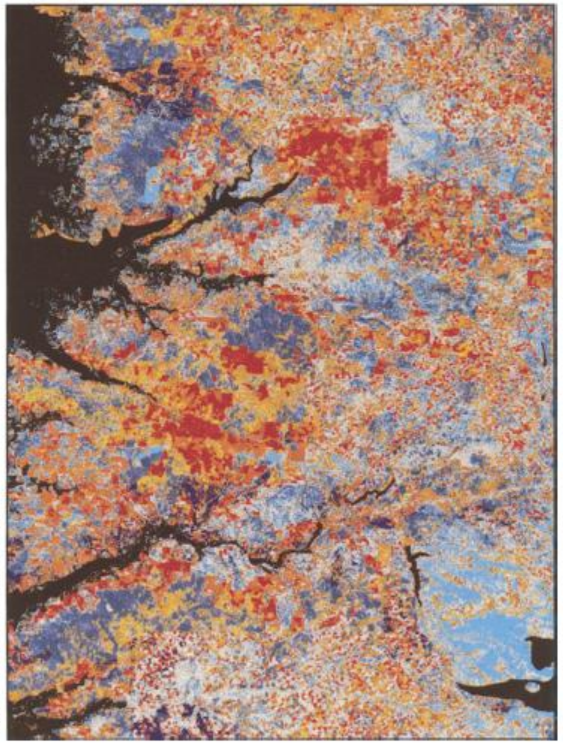
Estimates from a new modeling strategy

Warren B. Cohen, Mark E. Harmon, David O. Wallin, and Maria Fiorella

BioScience

American Institute of Biological Sciences

ACTING PUBLISHER	Donald R. Beem
EDITOR	Rebecca Chasan
FEATURES EDITOR	Anna Maria Gillis
MANAGING EDITOR	Rachel A. Russell
ASSISTANT EDITOR	Christina T. Maguire



Warren B. Cohen, USDA Forest Service

How will deforestation and other changes in land use affect global carbon cycles? Balancing the carbon budget is no easy task, in part because estimates of carbon flux rarely account specifically for all major forest carbon pools. Instead, they typically rely on uncertain generalizations of carbon production capacity and land use. In the article beginning on page 836, Warren B. Cohen and his colleagues describe a modeling strategy that uses satellite maps of forest harvest activity and vegetation cover, and spatial biogeoclimatic data, to come up with more rigorous estimates of net carbon flux. This map represents carbon flux over a 20-year period, beginning in 1972, of a portion of their pilot study area in the Pacific Northwest. The blue areas represent carbon sinks, the orange and red areas carbon sources. Gray areas had net carbon flux near zero. Detailed analyses of this type may allow forest managers to better predict how their decisions will influence regional carbon budgets.

Rebecca Chasan
—*Editor*

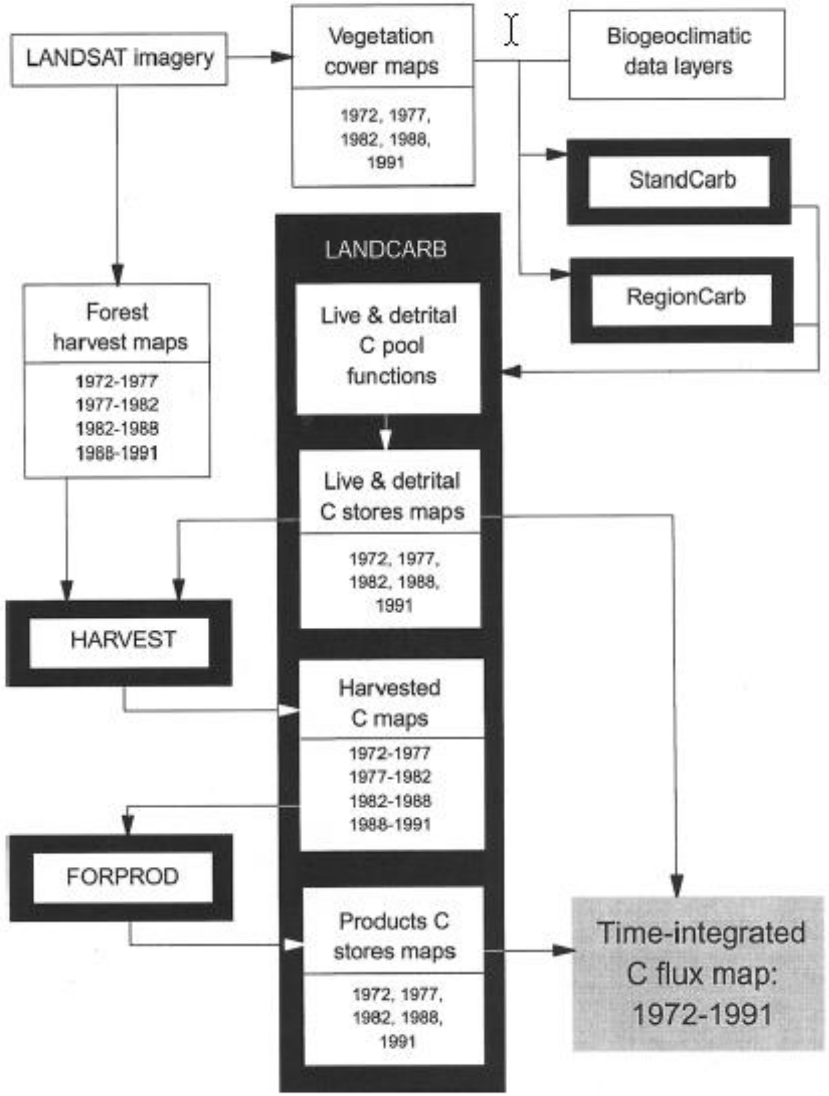


Figure 1. Schematic for the overall modeling strategy used to estimate carbon flux.

Why Am I a Strong Proponent of MSS?

- Demonstrating that regional forest management can be monitored with Landsat data (Cohen et al. 2002, *Ecosystems*)

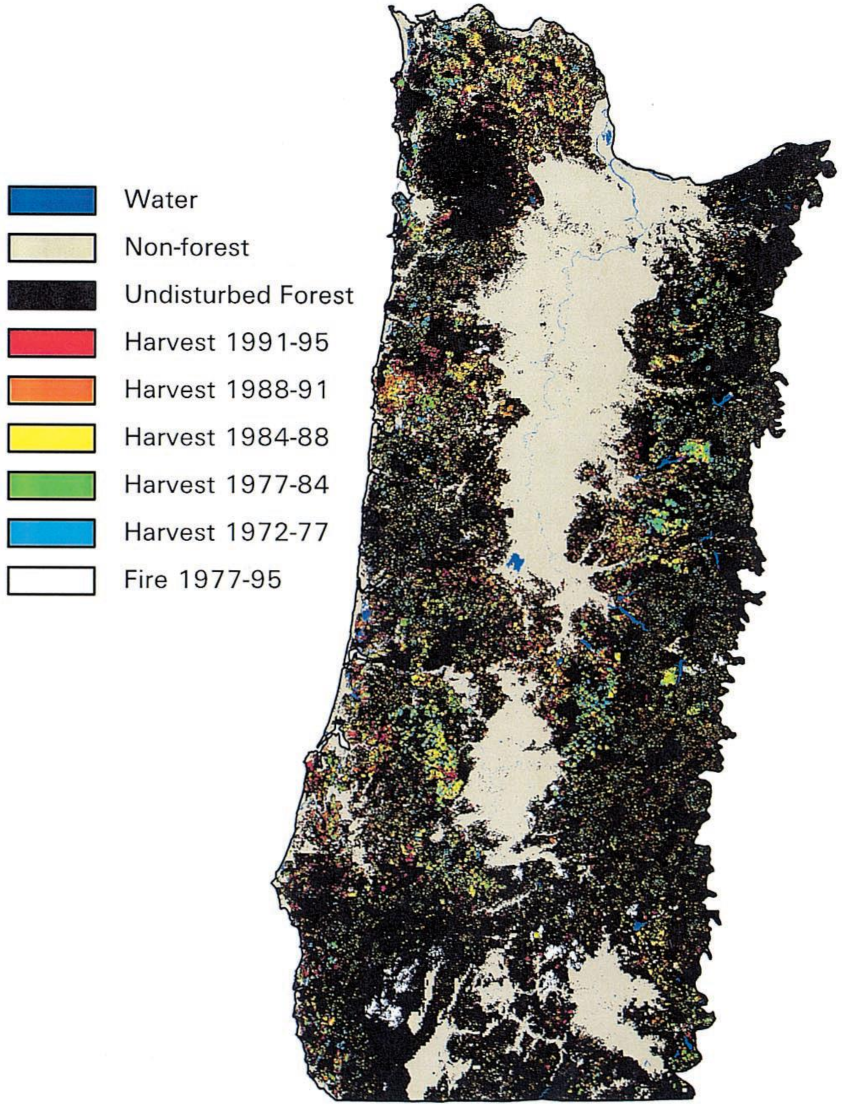
Ecosystems (2002) 5: 122–137
DOI: 10.1007/s10021-001-0060-X

ECOSYSTEMS

ORIGINAL ARTICLES

Characterizing 23 Years (1972–95) of Stand Replacement Disturbance in Western Oregon Forests with Landsat Imagery

Warren B. Cohen,[1]* Thomas A. Spies,[1] Ralph J. Alig,[1] Douglas R. Oetter,[2] Thomas K. Maiersperger,[2] and Maria Fiorella[2]



Why Am I a Strong Proponent of MSS?

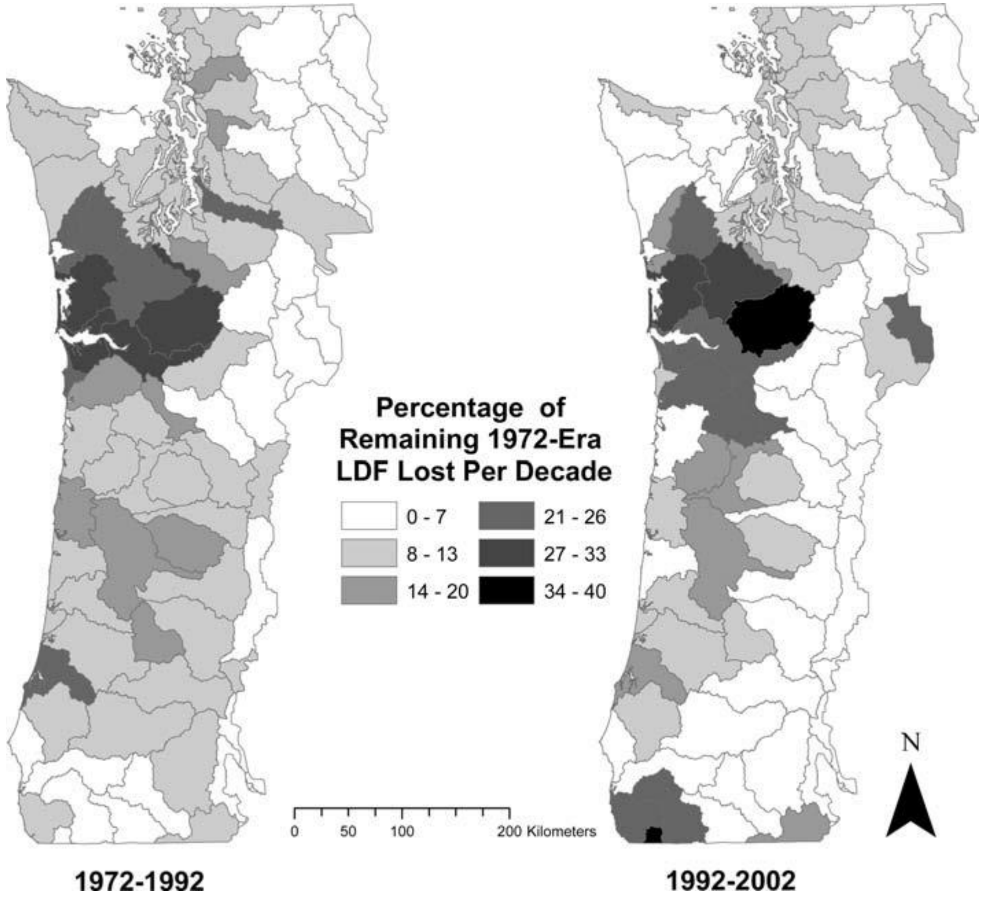
- Monitoring older forests for the Northwest Forest Plan (Healey et al. 2008, *Ecosystems*)

Ecosystems (2008) 11: 1106–1119
DOI: 10.1007/s10021-008-9182-8

ECOSYSTEMS

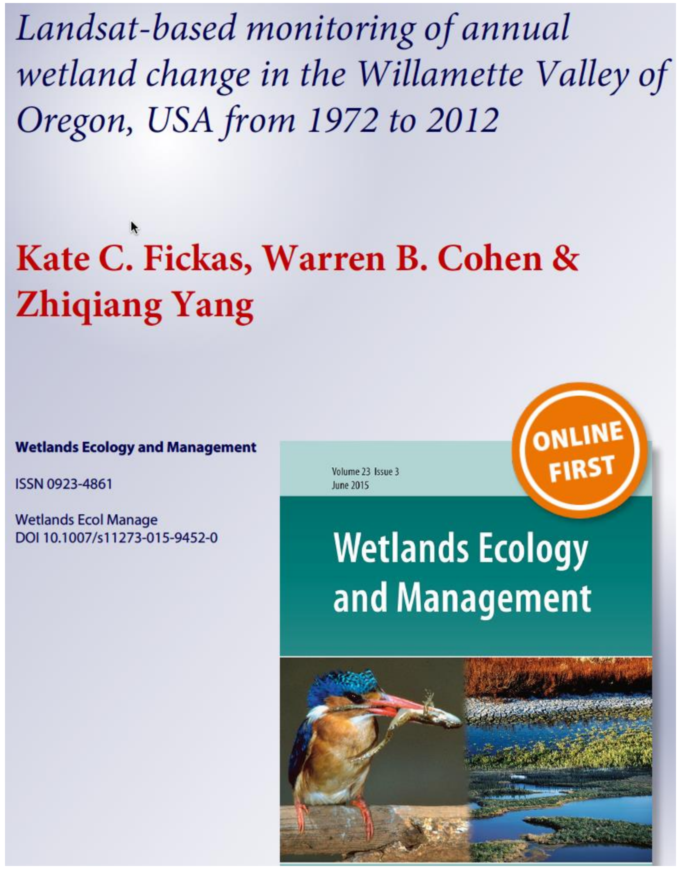
The Relative Impact of Harvest and Fire upon Landscape-Level Dynamics of Older Forests: Lessons from the Northwest Forest Plan

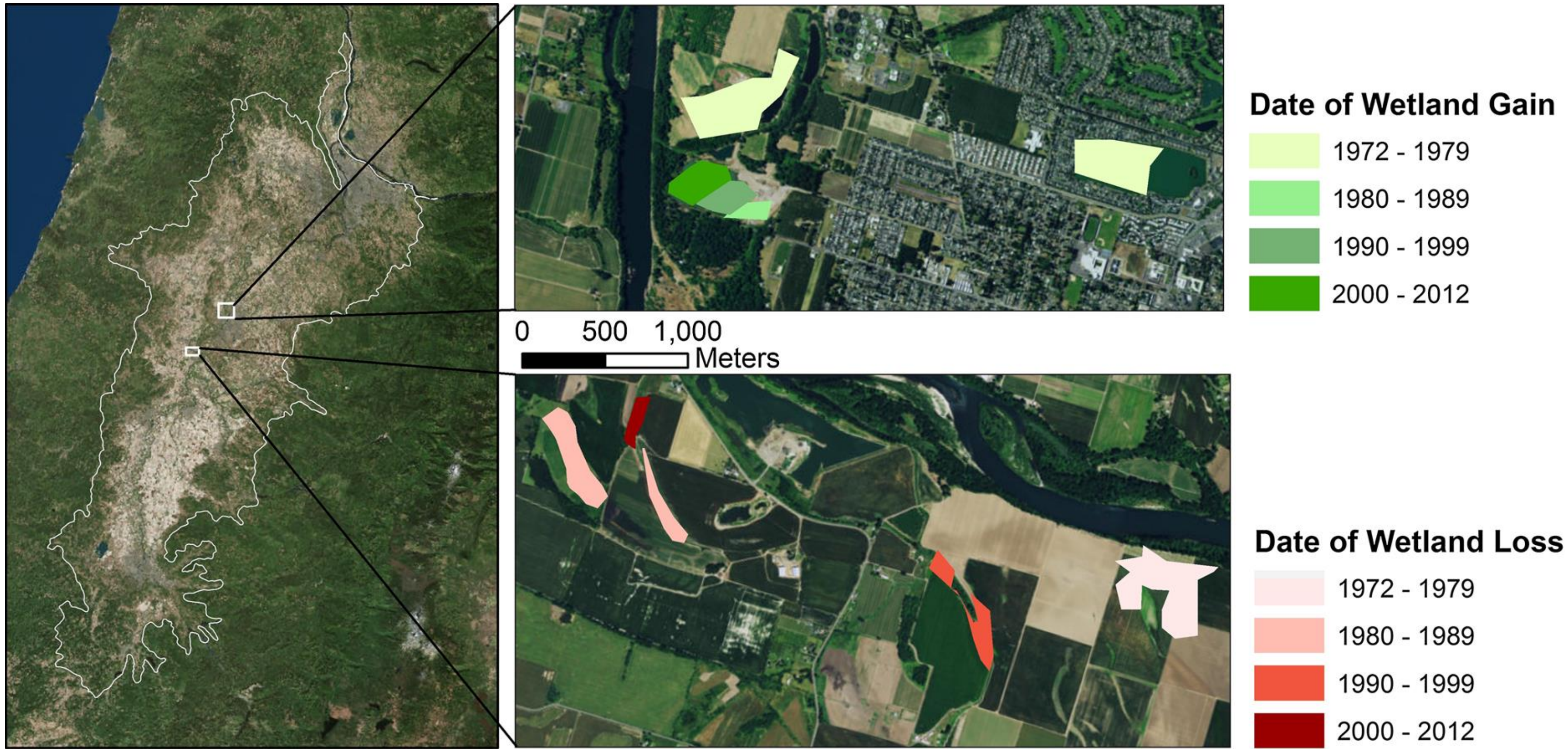
Sean P. Healey,[1]* Warren B. Cohen,[2] Thomas A. Spies,[2] Melinda Moeur,[3] Dirk Pflugmacher,[4] M. German Whitley,[2] and Michael Lefsky[5]



Why Am I a Strong Proponent of MSS?

- Effects of 1990 policy change to the Clean Water Act on annual trends in wetland change (Fickas et al. 2015, *Wetlands Ecology & Management*)

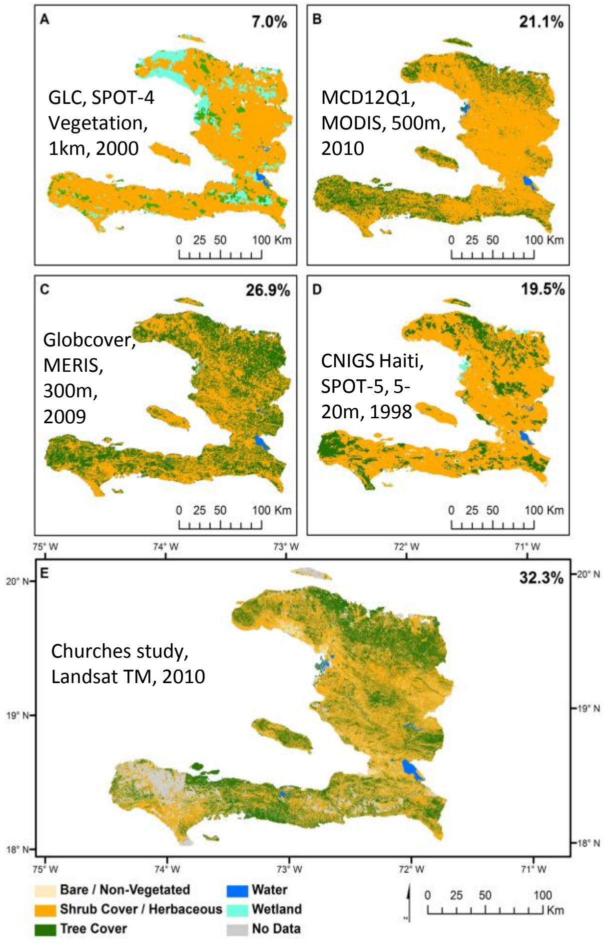


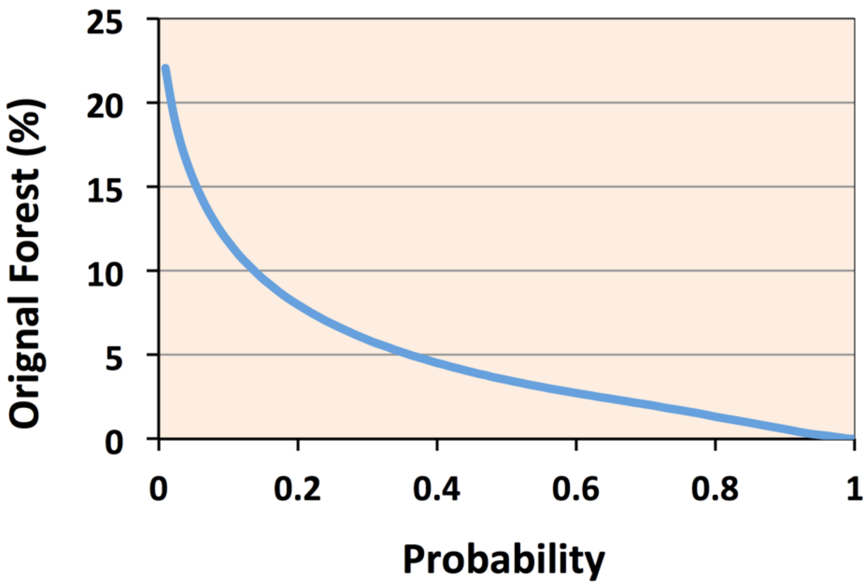


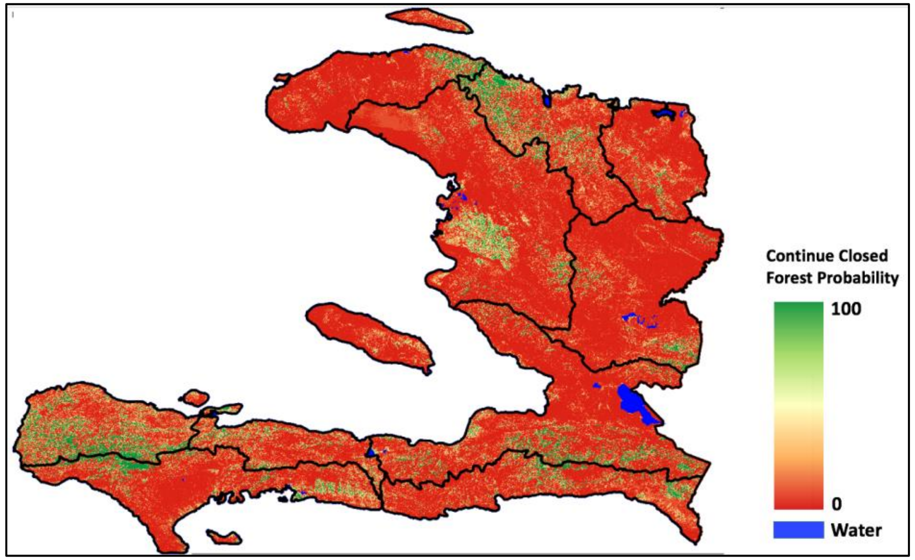
Why Am I a Strong Proponent of MSS?

- Mapping original forest cover in Haiti
  - Current estimates of forest cover based on single, recent date of Landsat (7-32%) miss the point that original forest is key to maintaining native biodiversity
  - We are using a time series approach based on MSS-OLI, characterizing long term, stable forest cover as a direct indicator of "unmanaged", native forest

From Churches et al. 2014, Int J Applied EO & GeoInf

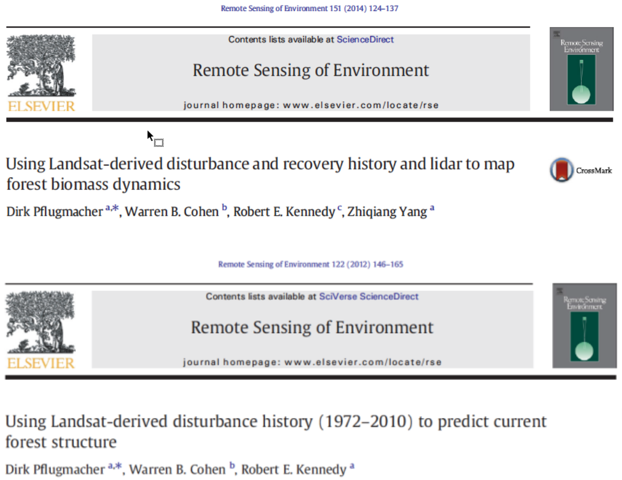






Why Am I a Strong Proponent of MSS?

- Forest disturbance and recovery history derived from Landsat time series can be use to derive biomass trajectories back to 1990
- Applications for REDD and national greenhouse gas reporting (NASA CMS)



Remote Sensing of Environment 151 (2014) 124–137
Contents lists available at ScienceDirect
Remote Sensing of Environment
journal homepage: www.elsevier.com/locate/rse

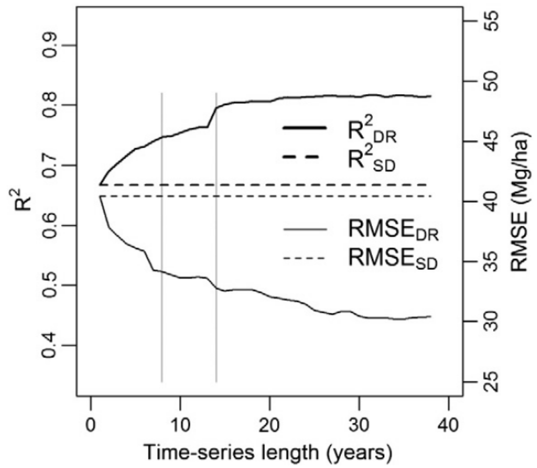
Using Landsat-derived disturbance and recovery history and lidar to map forest biomass dynamics

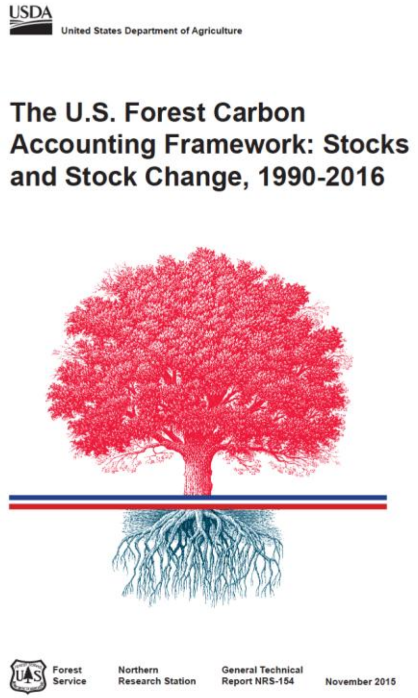
Dirk Pflugmacher [a,*], Warren B. Cohen [b], Robert E. Kennedy [c], Zhiqiang Yang [a]

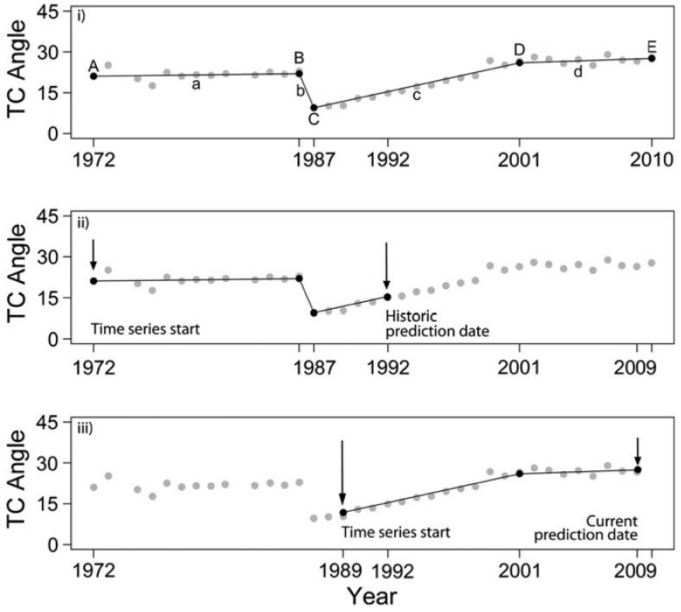
Remote Sensing of Environment 122 (2012) 146–165
Contents lists available at SciVerse ScienceDirect
Remote Sensing of Environment
journal homepage: www.elsevier.com/locate/rse

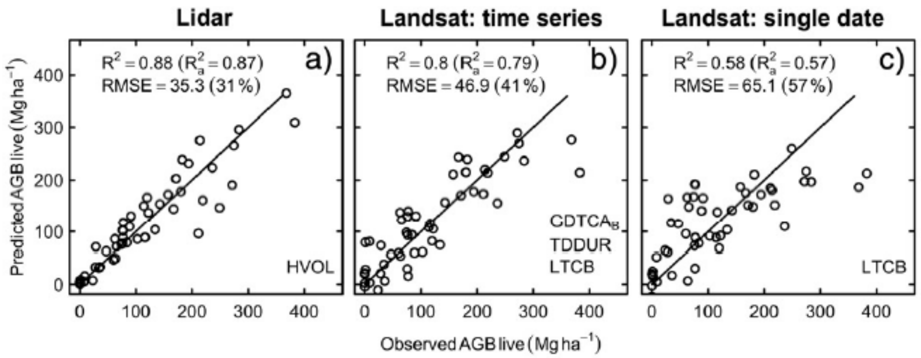
Using Landsat-derived disturbance history (1972–2010) to predict current forest structure

Dirk Pflugmacher [a,*], Warren B. Cohen [b], Robert E. Kennedy [a]









Other Motivations

- e.g. Doug Bolton….to follow

Community Vibe (Landsat value began in 1972)

- Woodcock et al. 2008. *Free Access to Landsat Data* (Science)
  - Free imagery will enable reconstruction of the history of Earth's surface back to 1972, chronicling both anthropogenic and natural changes during a time when our population doubled and the impacts of climate change became noticeable
- Wulder et al. 2008. *Landsat continuity: Issues and Opportunities for Land Cover Monitoring* (RSE)
  - Initiated in 1972, the Landsat program has provided a continuous record of earth observation for 35 years…..results in imagery that can be processed to represent land cover over large areas with an amount of spatial detail that is absolutely unique and indispensable for monitoring, management, and scientific activities
  - Without this information, we have no means of informing, nor of gauging the effectiveness, of our management strategies

More Good Vibe (Landsat value began in 1972)

- Roy et al. 2014. *Landsat-8: Science and product vision for terrestrial global change research* (RSE)
  - At over 40 years, the Landsat series of satellites provides the longest temporal record of space-based surface observations
  - Time series are calibrated to provide a characterized consistent record that is needed to enable discrimination between data artifacts and actual land surface temporal changes
  - Successful launch of Landsat 8…extends the 40-year Landsat record…further advancing global change research, while <u>protecting and maximizing the previous investments in Landsat</u>
  - Importance of continuity of the Landsat record…<u>Just as the Mauna Loa, Hawaii, atmospheric CO2 record is now considered a vital indicator of human activity…Landsat provides the longest consistent satellite terrestrial record</u>

Ongoing Support for MSS

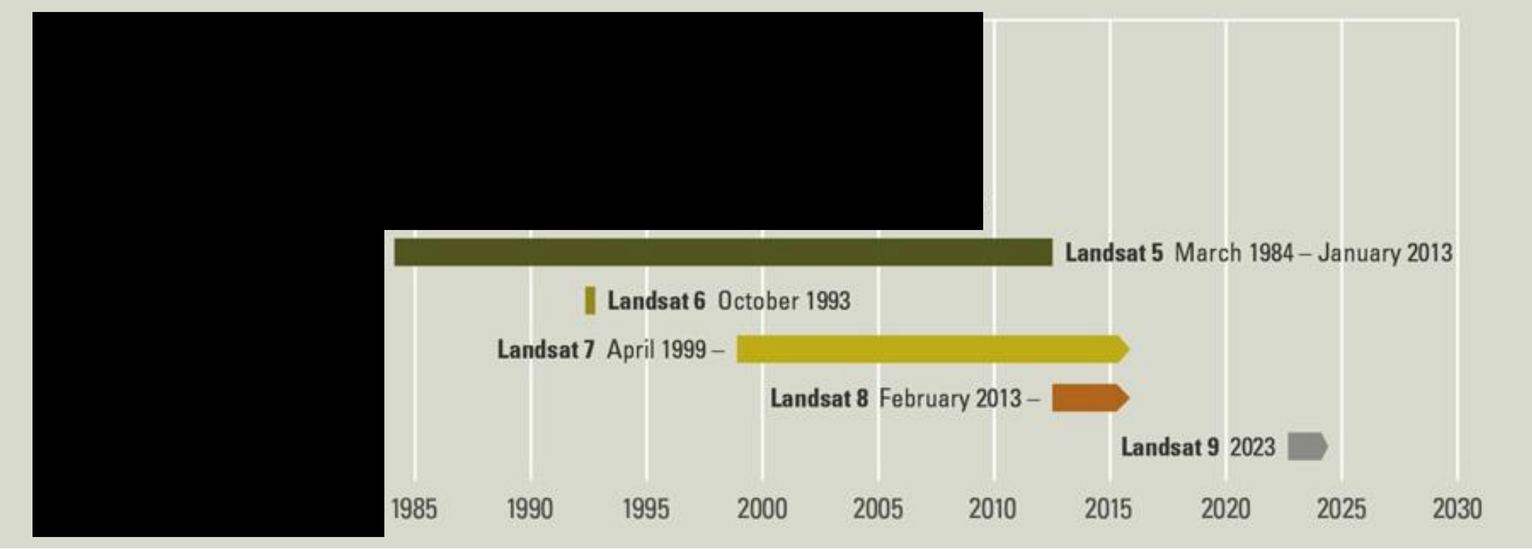
- Wulder et al. 2016. *The global Landsat archive: Status, consolidation, and direction* (RSE)
  - Describes current status of the LGAC program to produce a single consolidated archive of all Landsat data
  - Increased data holdings, systematic Landsat processing, free data access will provide improved opportunities for local to global spatial scale, multi-decadal Landsat-based applications and science that include MSS data
- Vogelmann & Gallant. 2016. *Perspectives on Monitoring Gradual Change Across the Continuity of Landsat Sensors Using Time-Series Data* (RSE)
  - Eventual expansion of time-series analyses to include data from the MSS archive will provide us with more than 43 years of continuous coverage at scales relevant to natural resource planners and managers

The Support Continues

- Richard Allen, pers. comm. Dec. 2015. *On the value of MSS for documenting historical water use during 1972-1984.*
  - Idaho Dept. of Water Resources considering <u>use of MSS to document historic water use </u>using VI tuned using thermal imagery and METRIC
  - Early investigation suggests NDVIs from L5 MSS and TM based on latest calibrations are VERY closely matched (now, if we can just manufacture that thermal data, we'll be in business)
- Leo Lymburner, pers. Comm. Dec. 2015. *On the value of MSS for historic analysis of total suspended solids.*
  - Need NBAR, cloud screened data to fit processing stream

Time for USGS to Act?

- http://landsat.usgs.gov/NewMSSProduct.php
    - ***<u>Eventually</u>**, a consistent, cross-calibrated archive of Landsat data will be available, as increasing knowledge of this oldest dataset expands and trending continues…This large-scale effort may require regular reprocessing of MSS data*

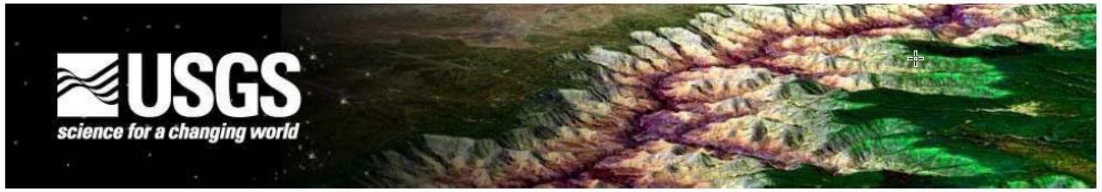


Engineering Challenges

- MSS only one of many

Many Challenges

- How to Provide All Data Online
    - Reprocessing in the Cloud?
    - Processing Support from Partners?
- What is the best solution for rapid access of the data cube for land change detection and other algorithms?
    - Technologies / Approaches?
- How to Create a more *Flexible* Architecture
    - Distributed Archives, Processing, and/or Storage?
- MSS data from Landsats 1-5
    - Enable pixel-level analysis on all MSS data!
- Cross-Platform Exploitation
    - E.g. Landsat and Sentinel 2
- Future Missions
    - Long-Term Vision to Extend Landsat Data Record for Decades to Come



The USGS Landsat Big Data Challenge

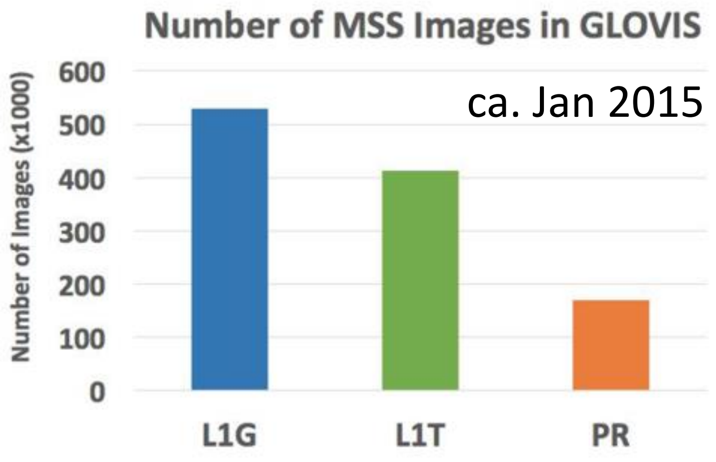
Brian Sauer
Engineering and Development
USGS EROS
bsauer@usgs.gov

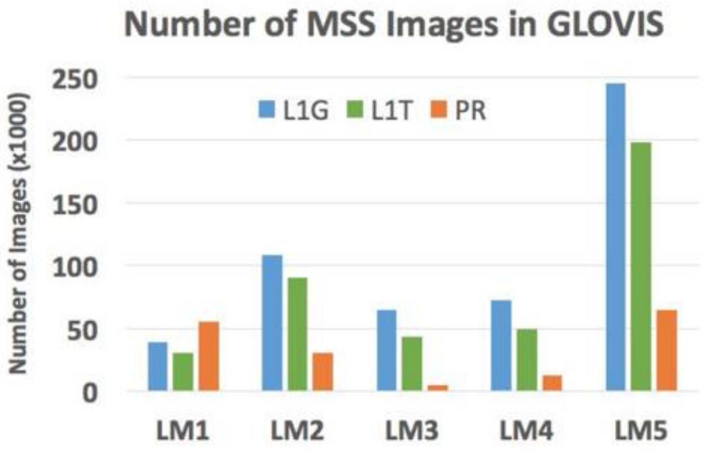
Science Solution (one approach from an impatient scientist) – Required Steps

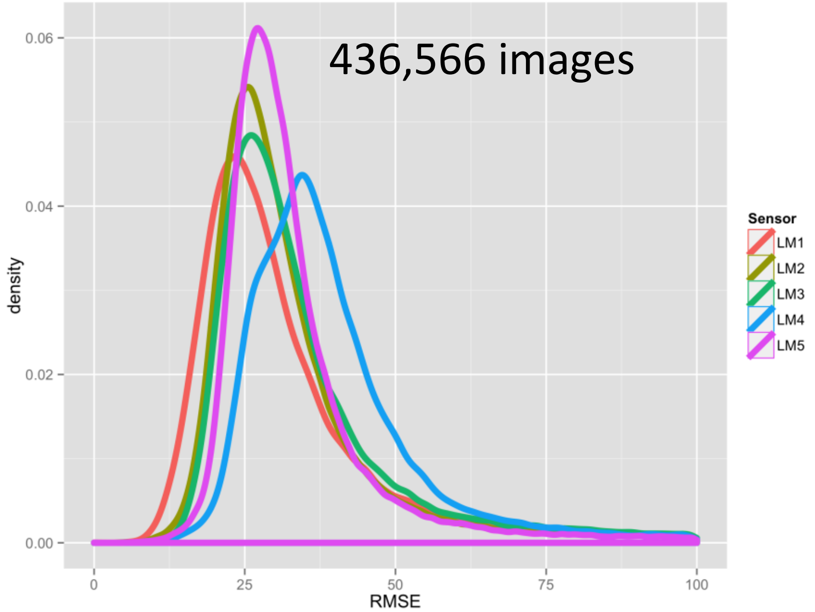
- Radiometric calibration – As best as possible and getting better
  - Marham and Helder 2012 (RSE); Helder et al. 2012 (IEEE)
  - More from Dennis on this in follow-on discussion

Science Solution– Required Steps

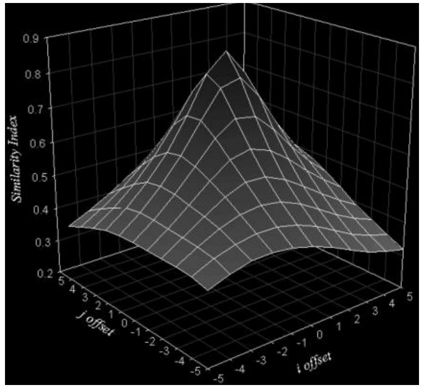
- Geometric correction – Room for improvement
  - <40% L1T; many with high RMSE







  - Imperfect and partially functional solution
    - Autocorrelation tie points solution (Kennedy and Cohen 2003, IJRS); automated for L1T (Justin)
  - Yongwei Sheng solution to follow



Science Solution – Required Steps

- Cloud Masking (http://www.msscvm.jdbcode.com/index.html)

MSScvm: An automated system to created cloud and cloud shadow masks for Landsat MSS imagery.

Learn more

Remote Sensing of Environment 169 (2015) 128–138

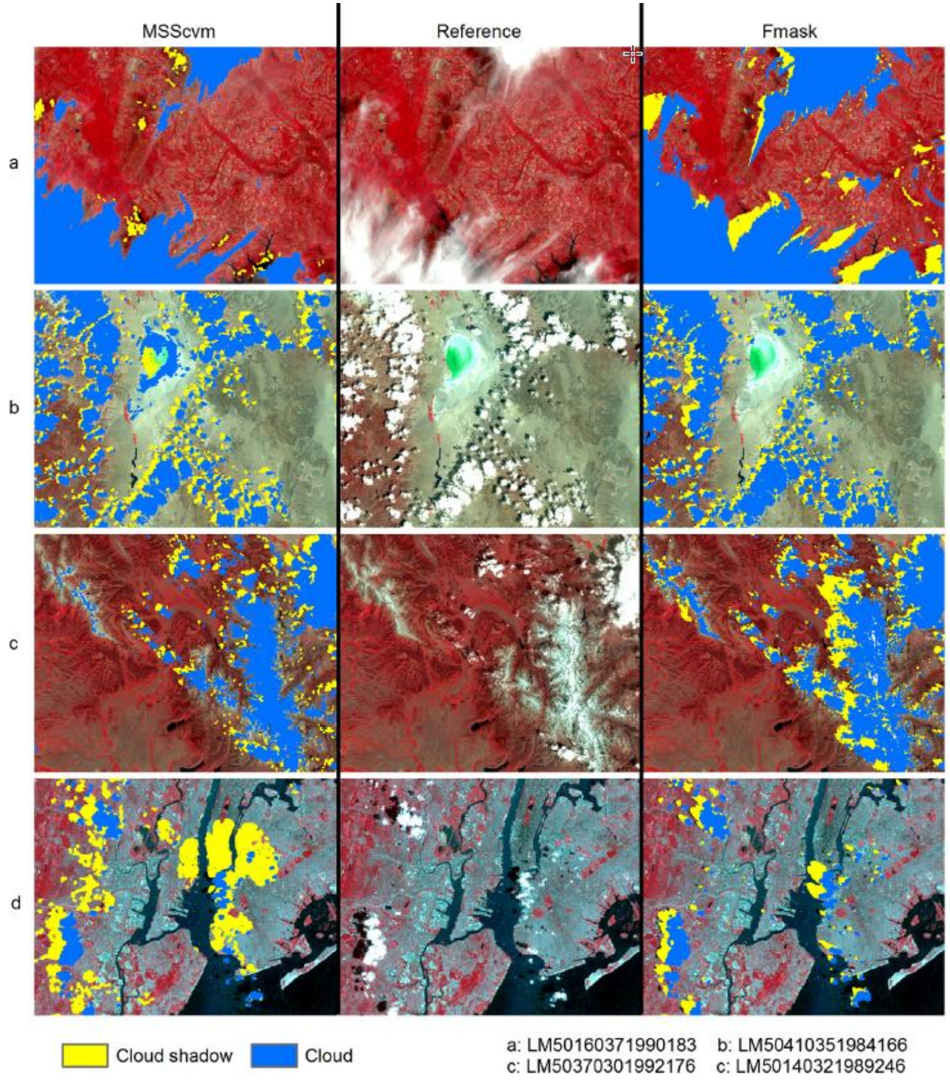
Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

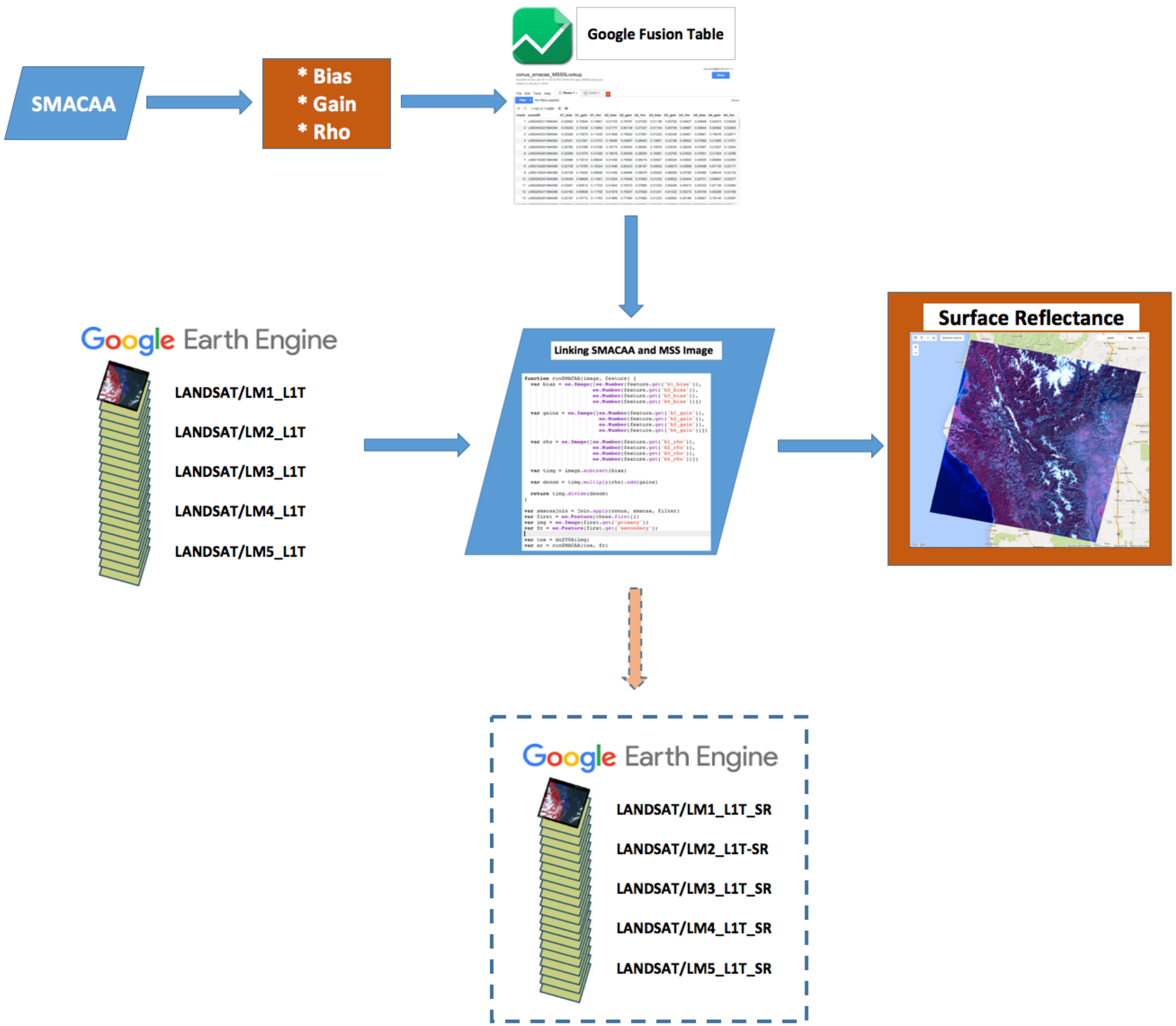
Automated cloud and cloud shadow identification in Landsat MSS imagery for temperate ecosystems

Justin D. Braaten [a,*], Warren B. Cohen [b], Zhiqiang Yang [a]



Science Solution – Required Steps

- Surface reflectance (workflow – in progress)
  - CONUS now
  - Global ???
- More from Dennis on this in follow-on discussion



Time Series Analysis Pathways (MSS→OLI)

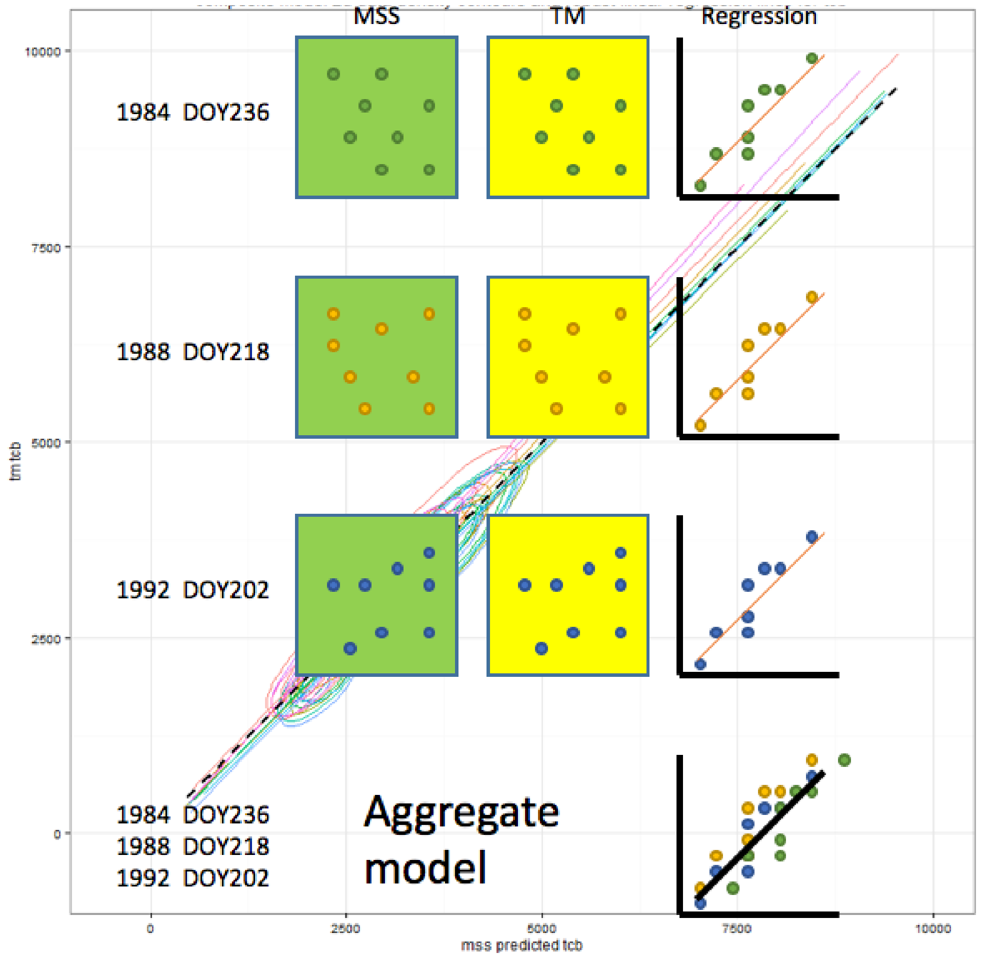
- Post change detection splicing – fallback option
- Spectral harmonization – preferred option

Time Series Analysis Pathways

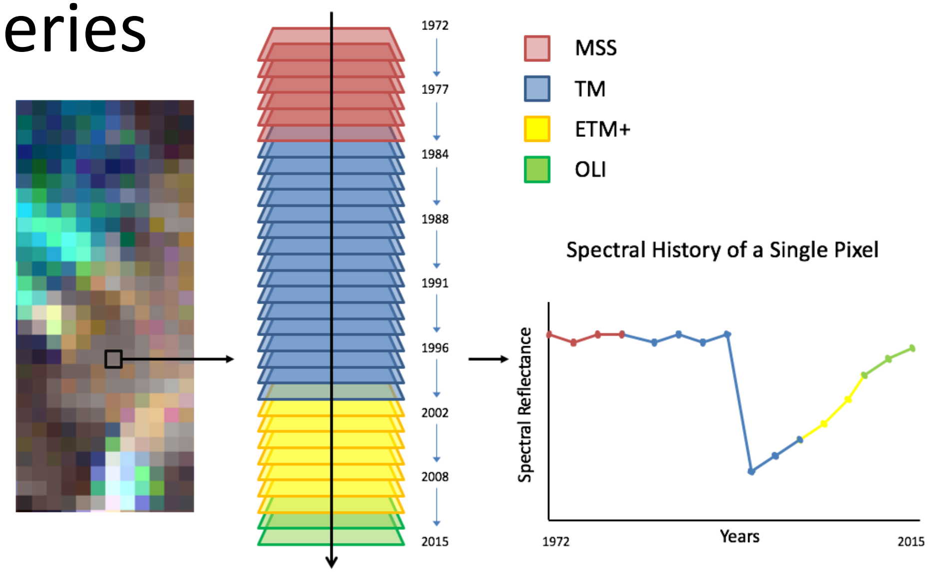
- Post change detection splicing – fallback option
  - Run time series change algorithm on MSS (1972 – 1992/95) using <u>native SR data</u>
  - Run same analysis on TM/ETM+ (1984 - ~2018/20)
  - Repeat on OLI (2013 - ?)
  - Reconcile differences in temporal overlap regions

Time Series Analysis Pathways: Spectral Harmonization

LandsatLinkr::MSScal (Braatan)

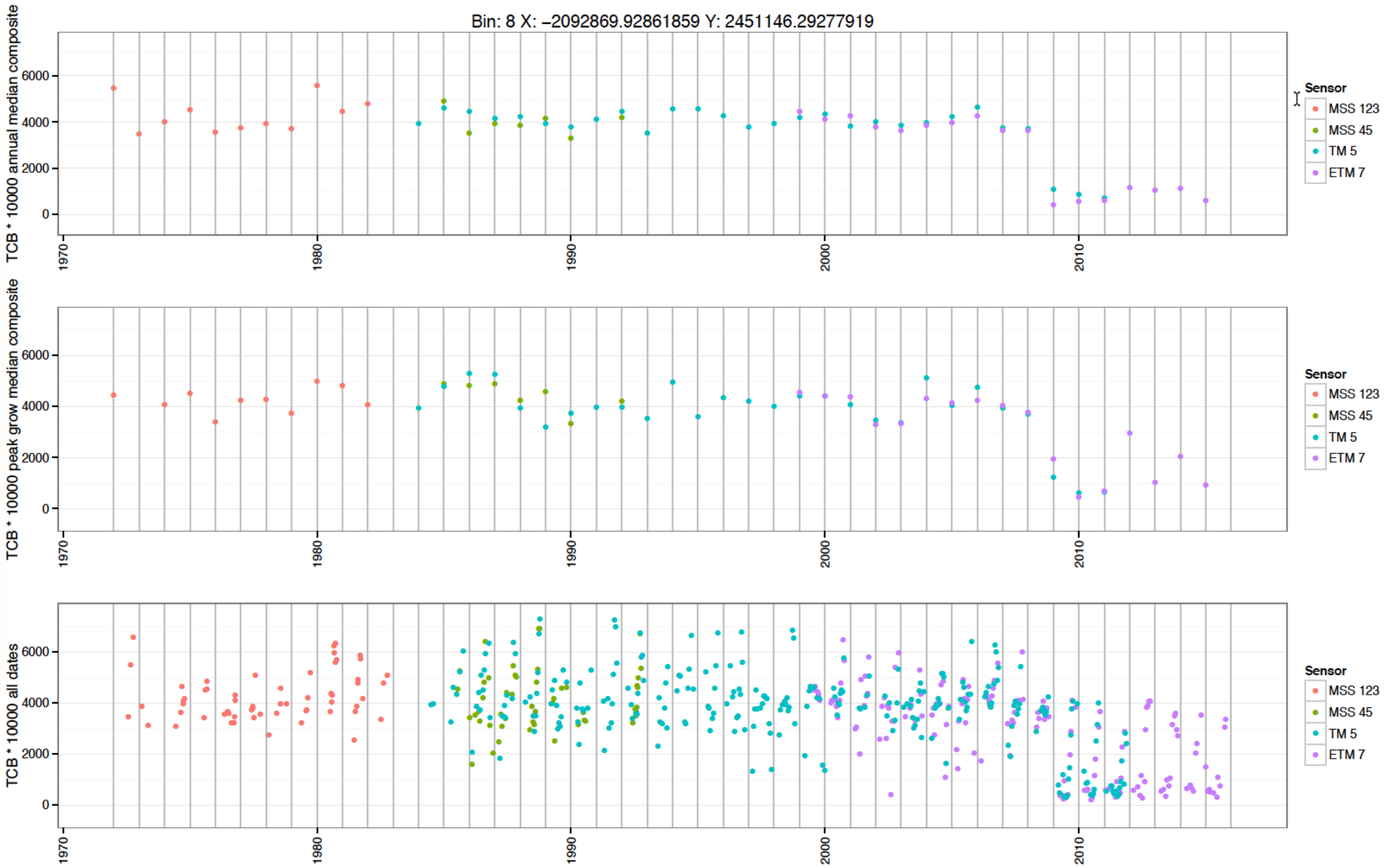


Goal: single, per-pixel spectral series



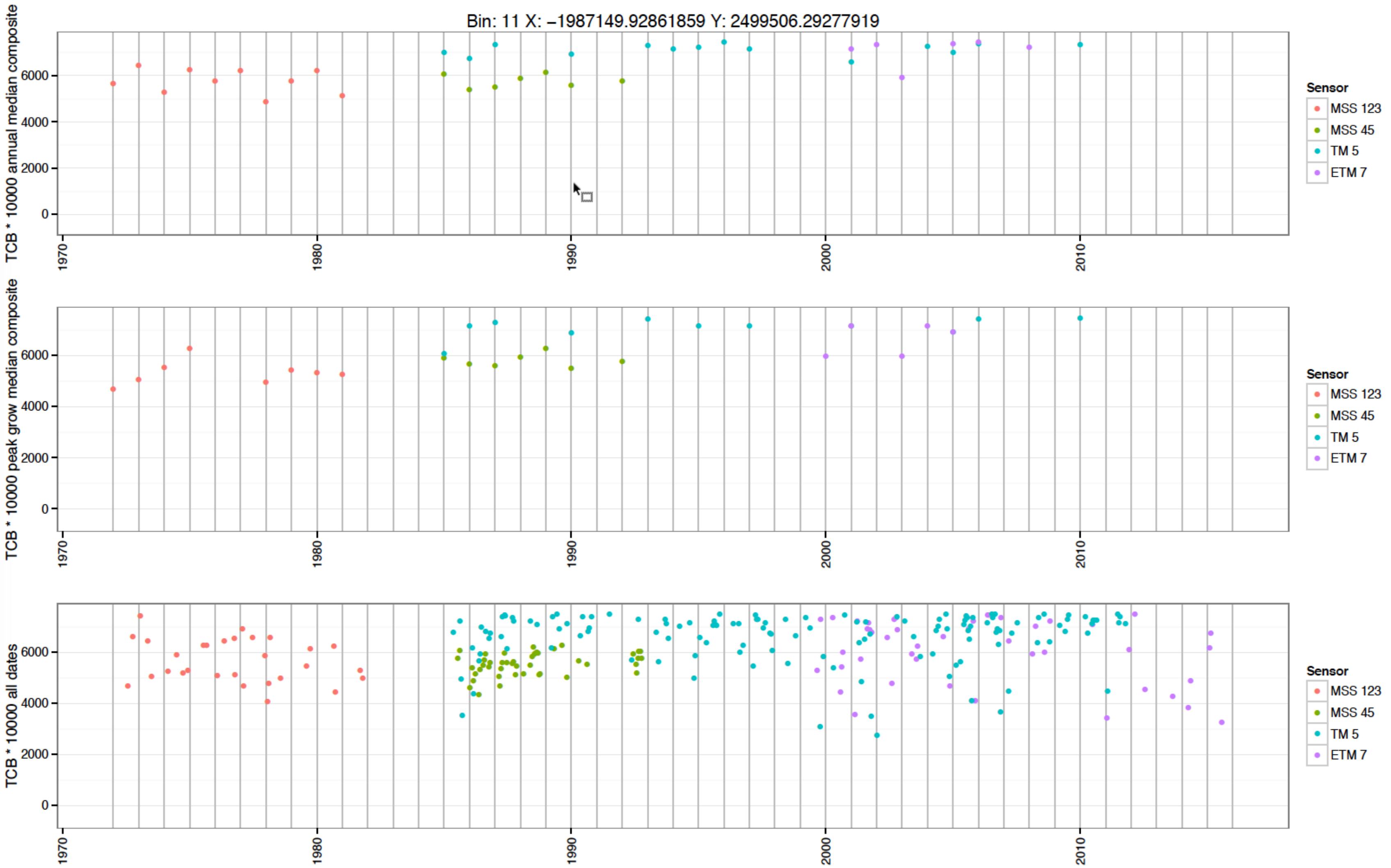
- ***Band/spectral index* statistical modeling**
  - Random Forest example: cross-temporal (all seasons and years) and space (currently scene level) approach, applied at pixel level

Single pixel (#70) example: 45/30 (OR – MSS-ETM+)



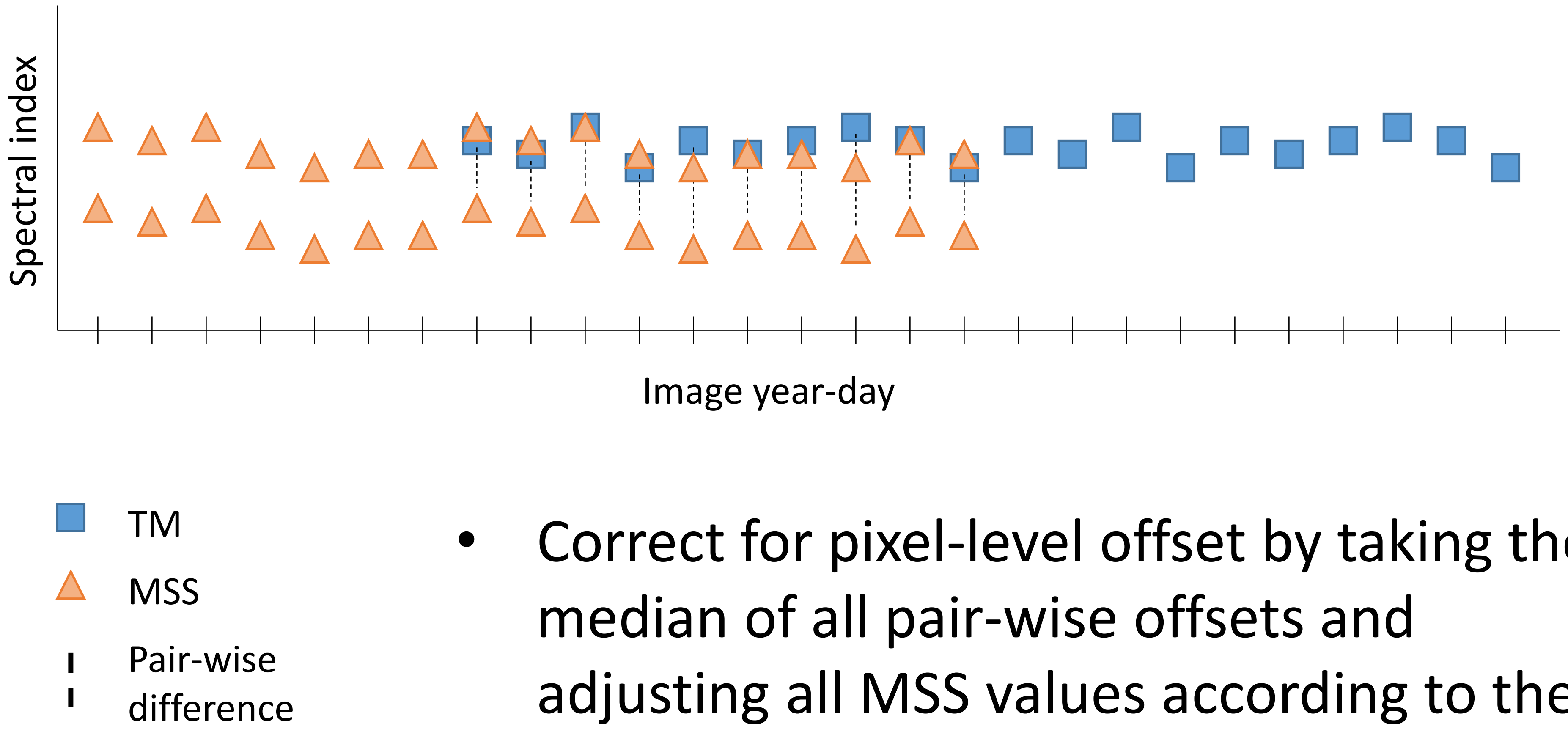
- Tasseled Cap brightness x 10,000 (cloud screened)
- Top & middle, two annual composites
- Bottom, all data
- <u>Note relative stability until change in 2009</u>

Single pixel (#95) example: 45/30 (OR – MSS-ETM+)



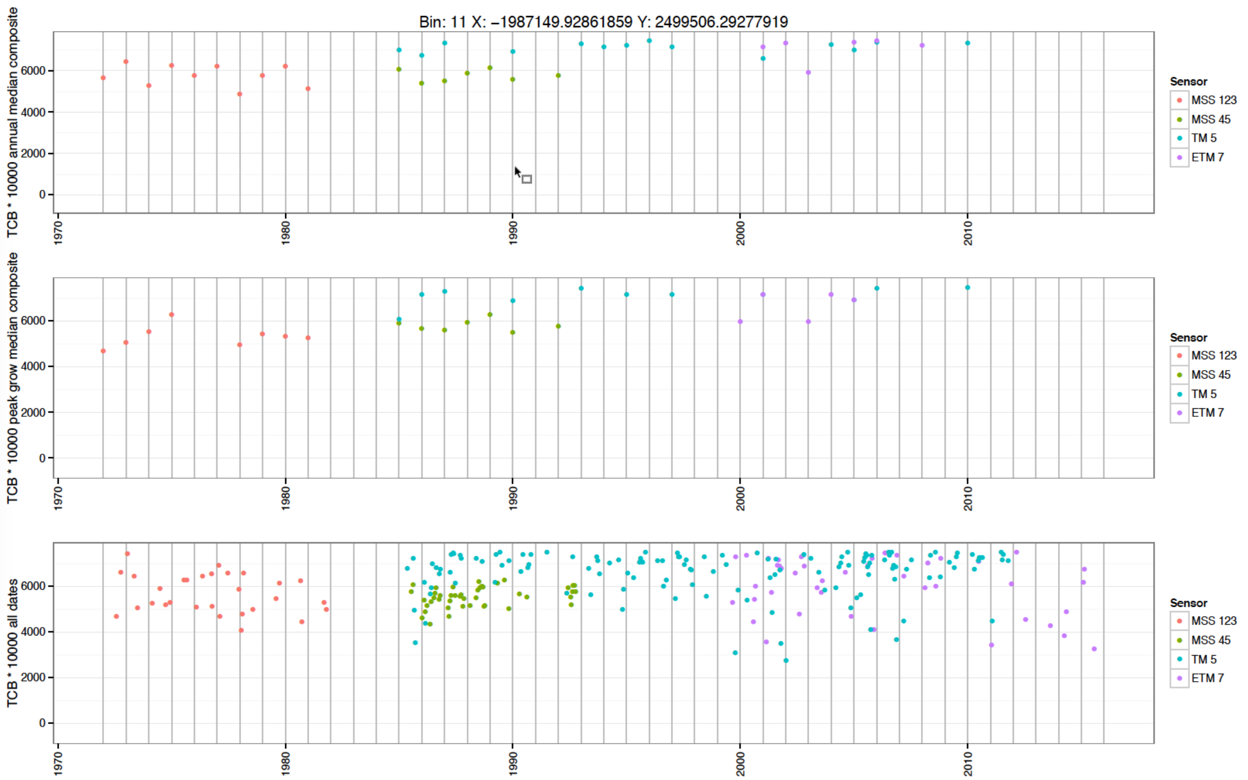
- Tasseled Cap brightness x 10,000 (cloud screened)
- Top & middle, two annual composites
- Bottom, all data
- Note bias in overlap region

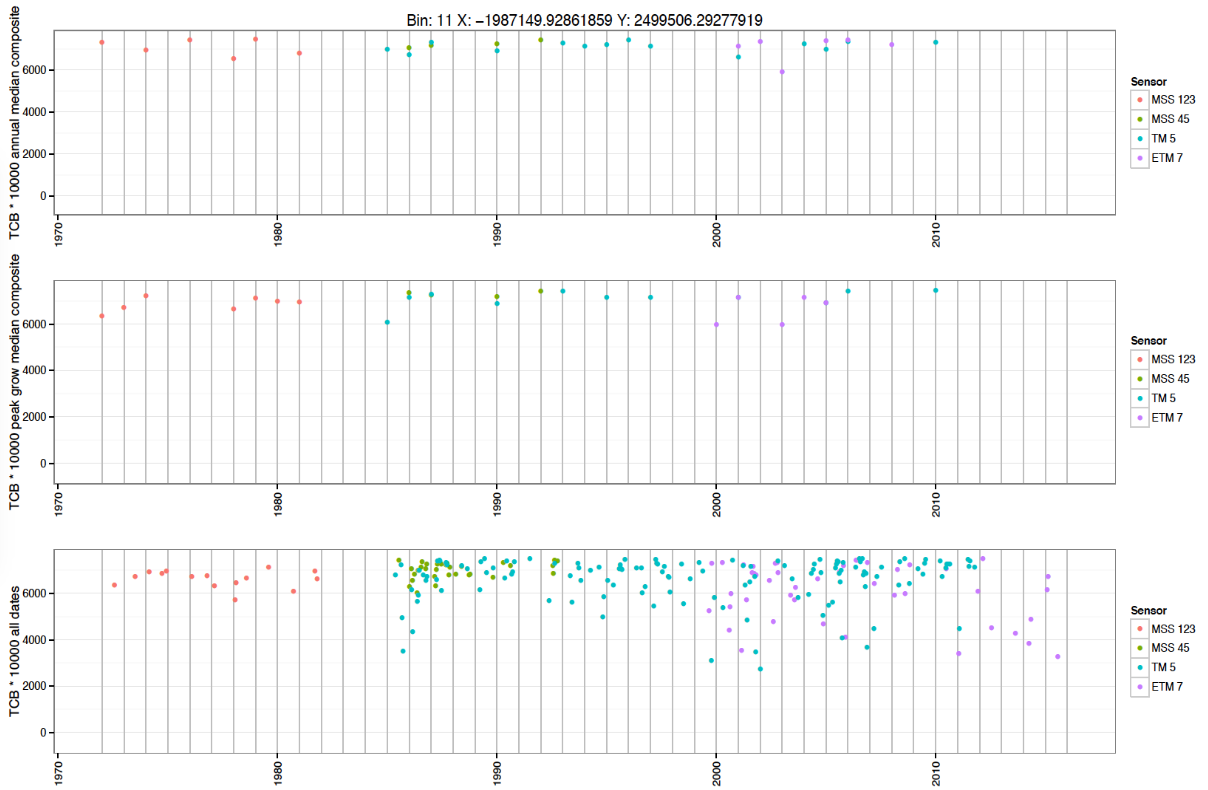
Pixel-level bias correction



- Correct for pixel-level offset by taking the median of all pair-wise offsets and adjusting all MSS values according to the result (from Pflugmacher et al. 2012, RSE)

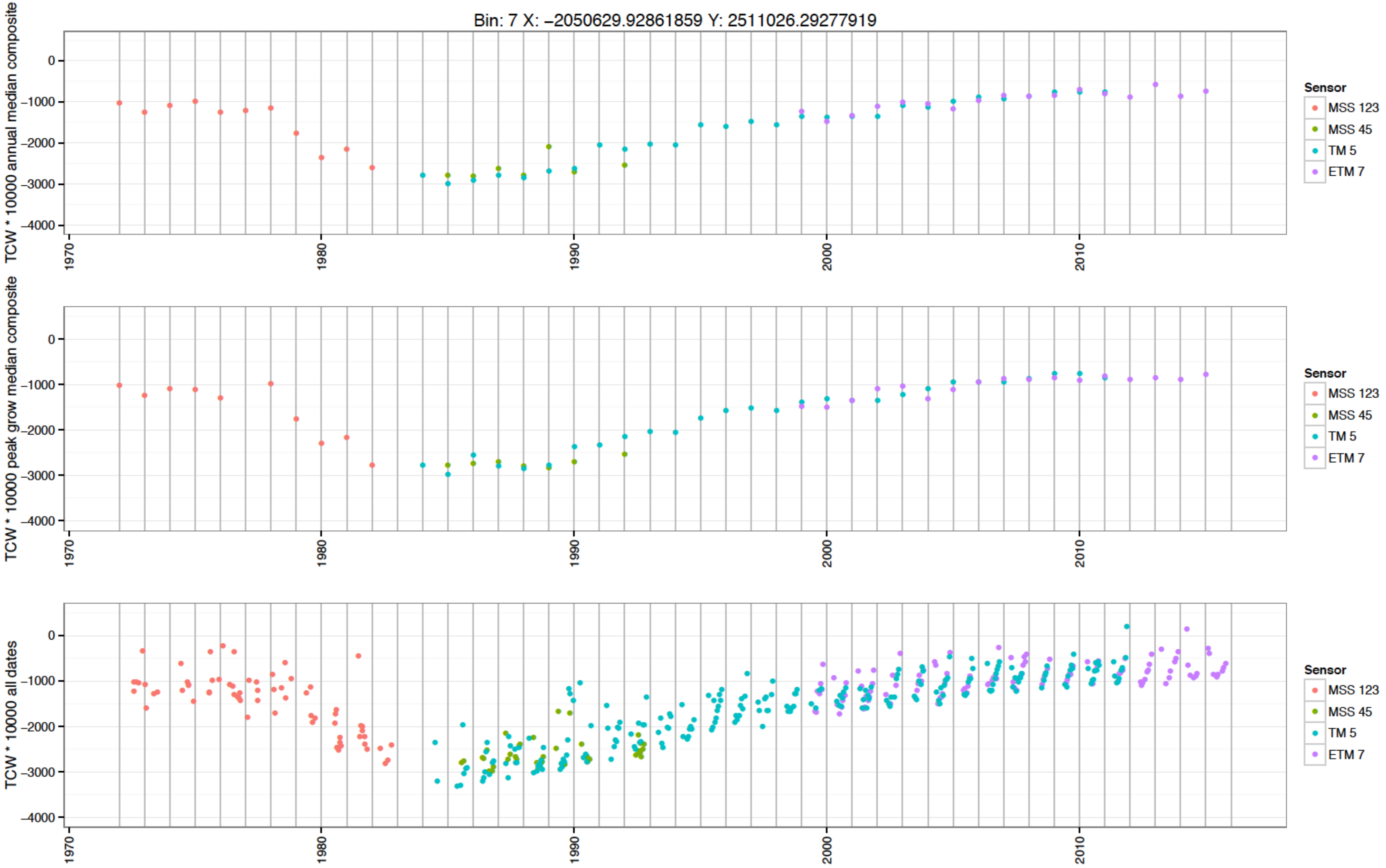
Single pixel (#95) example: 45/30 (OR – MSS-ETM+)





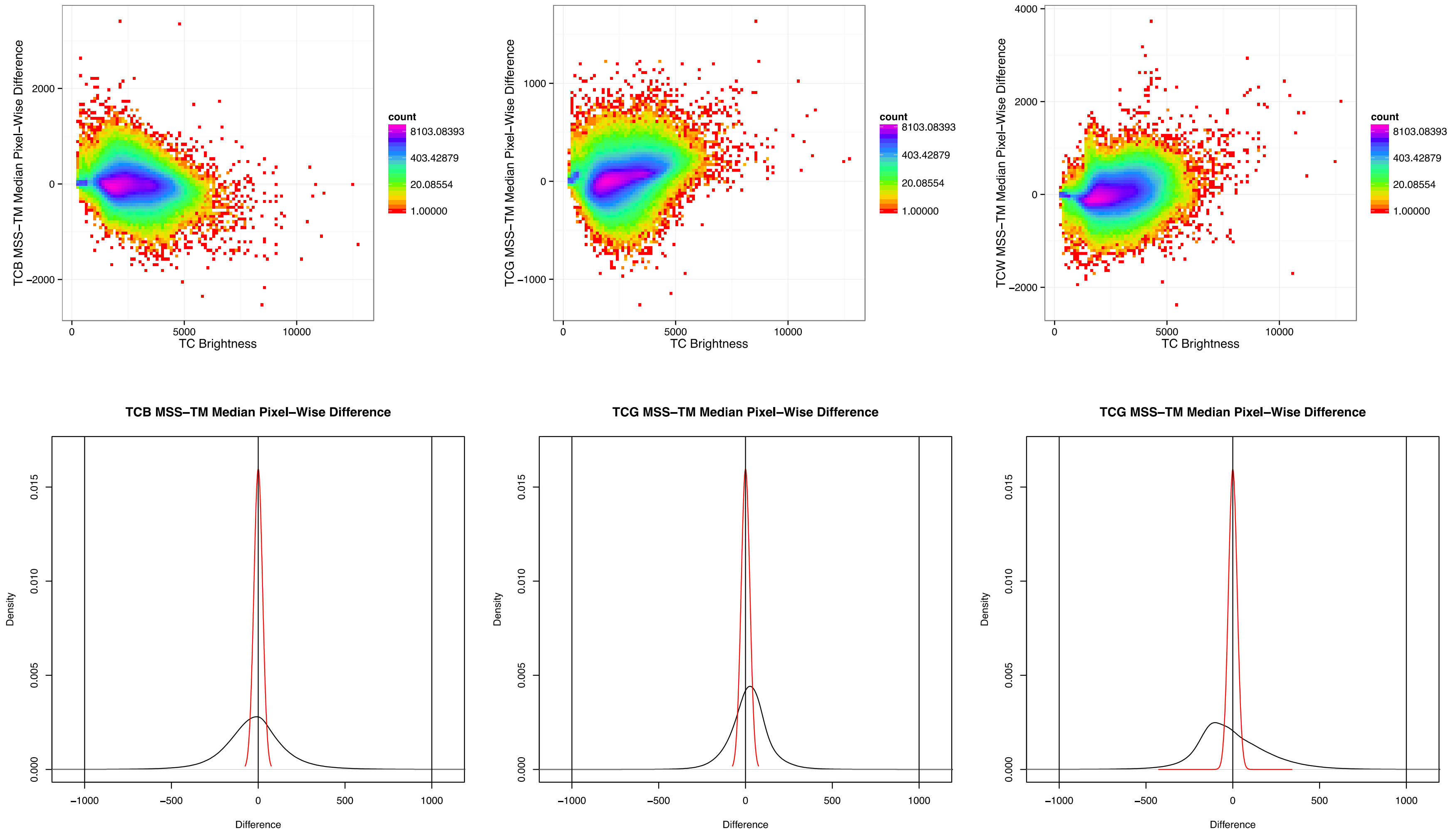
- Tasseled Cap brightness x 10,000 (cloud screened), top & middle, two annual composites, bottom, all data
- <u>Note bias (left) and bias corrected (right) in overlap region</u>

Single pixel (#95) example: 45/30 (OR – MSS-ETM+)



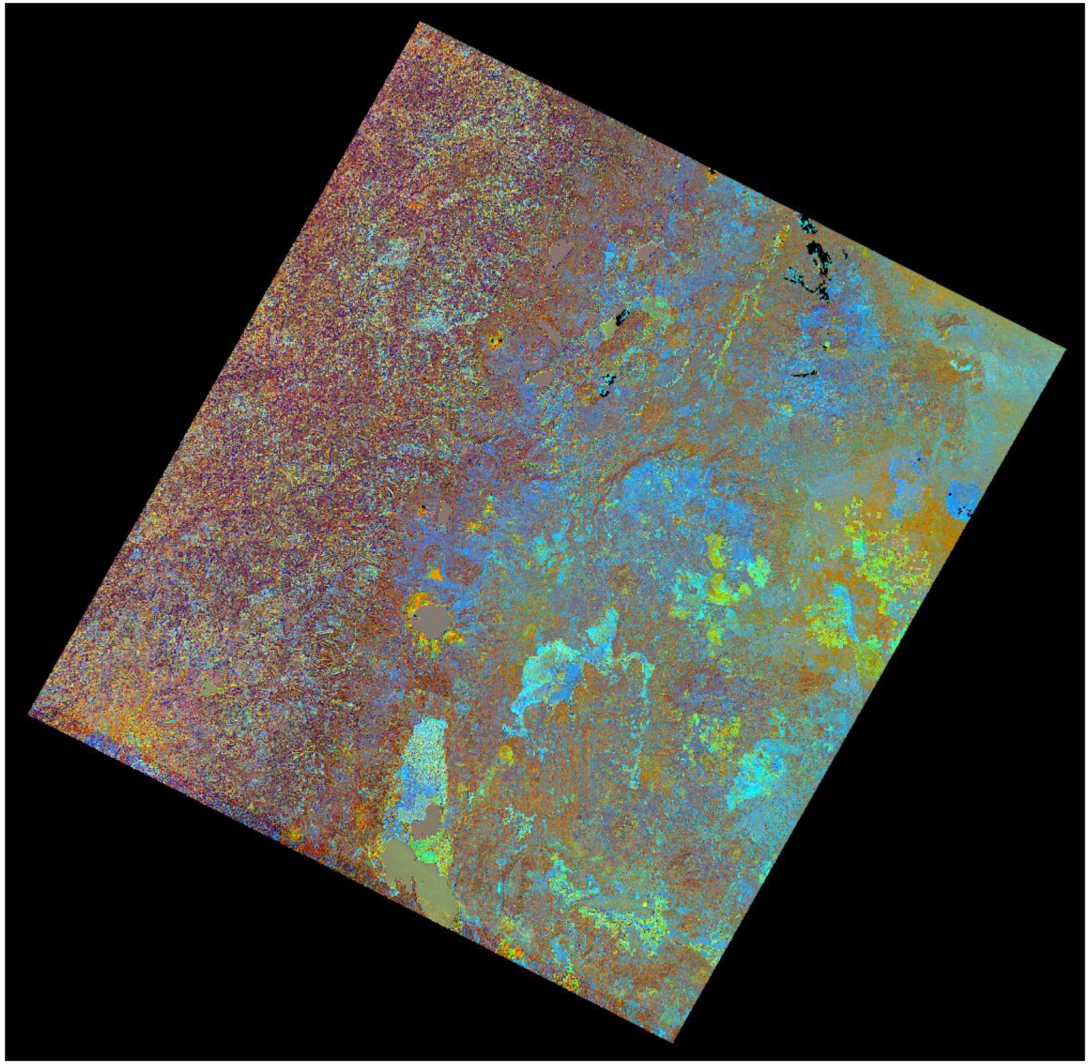
- Tasseled Cap <u>wetness</u> x 10,000 (cloud screened, bias corrected)
- Note <u>gradual change</u> from 78-82, post-87-~2010

Bias distribution across pixels



- Bias in Tasseled Cap brightness (left), greenness (middle), wetness (right) as function of 1985 brightness
- <u>Most bias values very low before adjustment</u> (well less than 0.005)
- <u>After adjustment all values near zero</u> (round-off error)

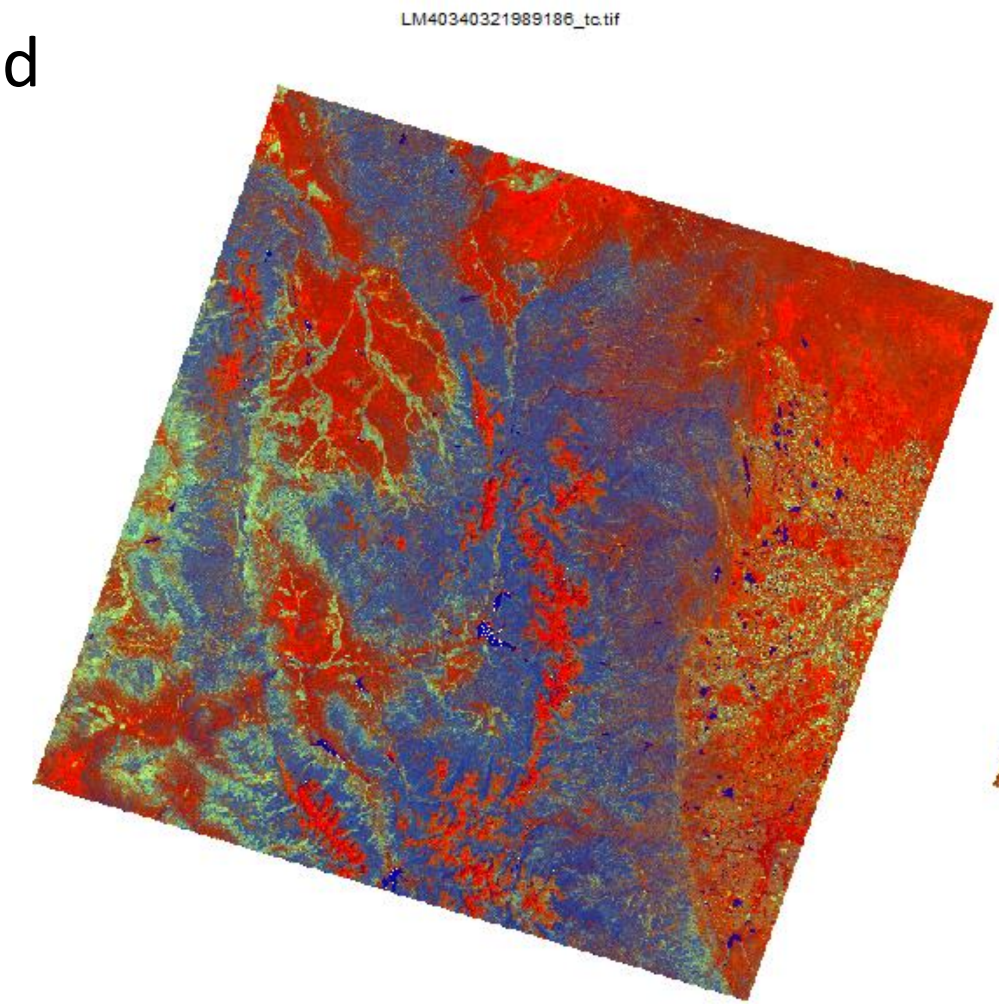
Tasseled Cap B,G,W (RGB) bias image

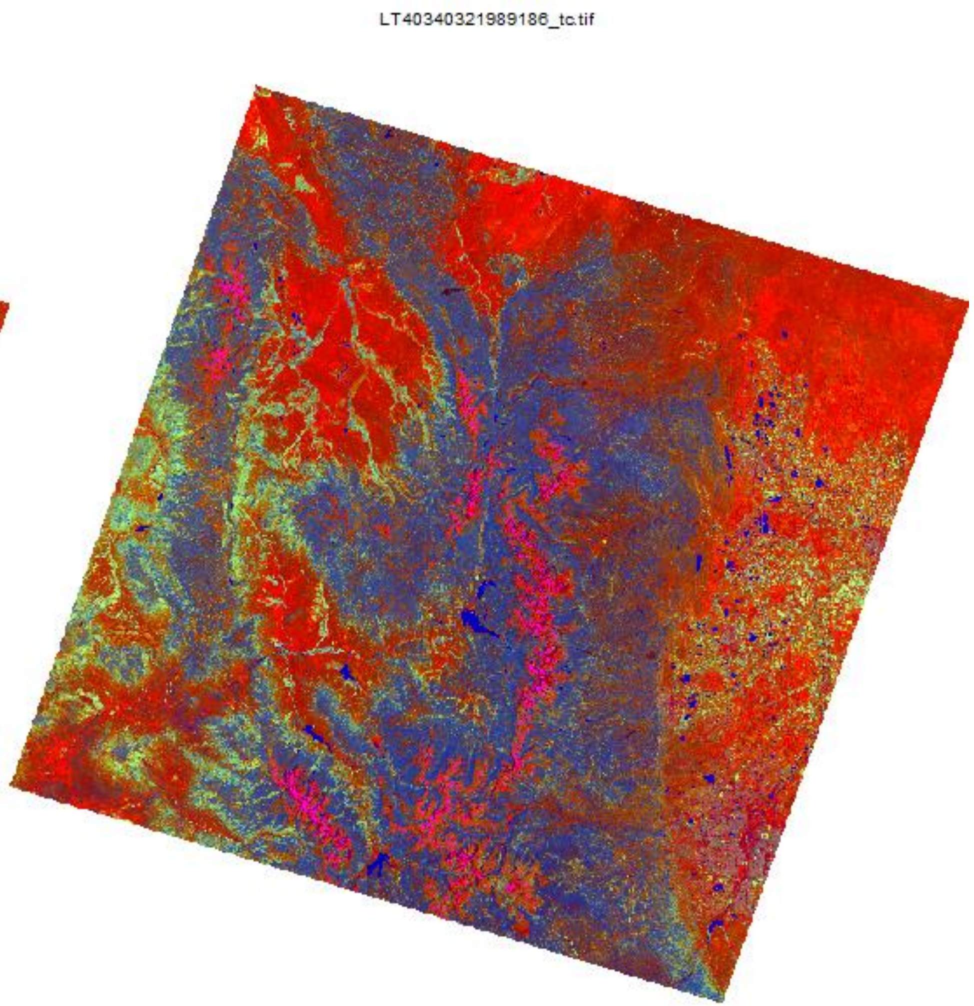


- Note land cover effect
- Additional justification for bias correction

Tasseled Cap B,G,W (RGB) coincident images (1989, DOY 186)

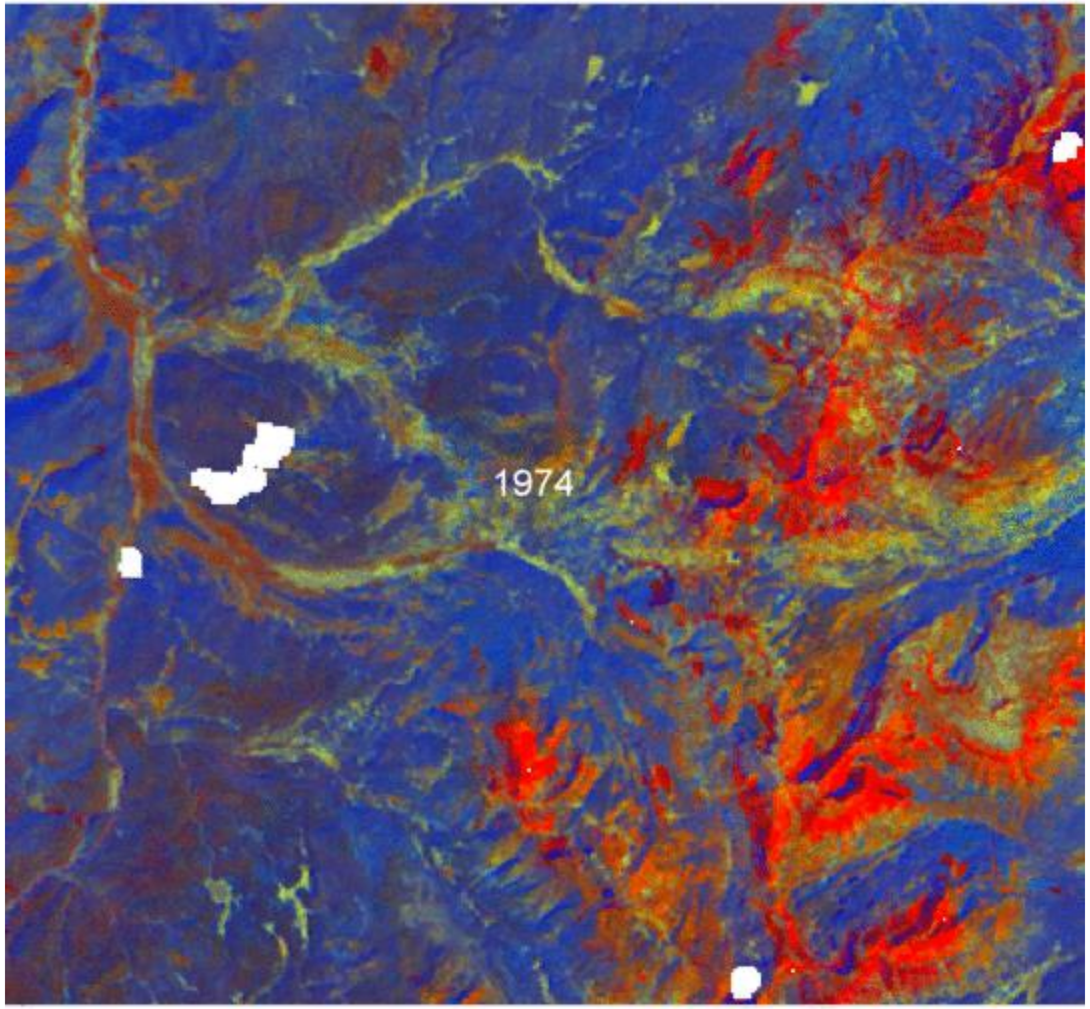
- Standardized stretch
- CO (35/32)





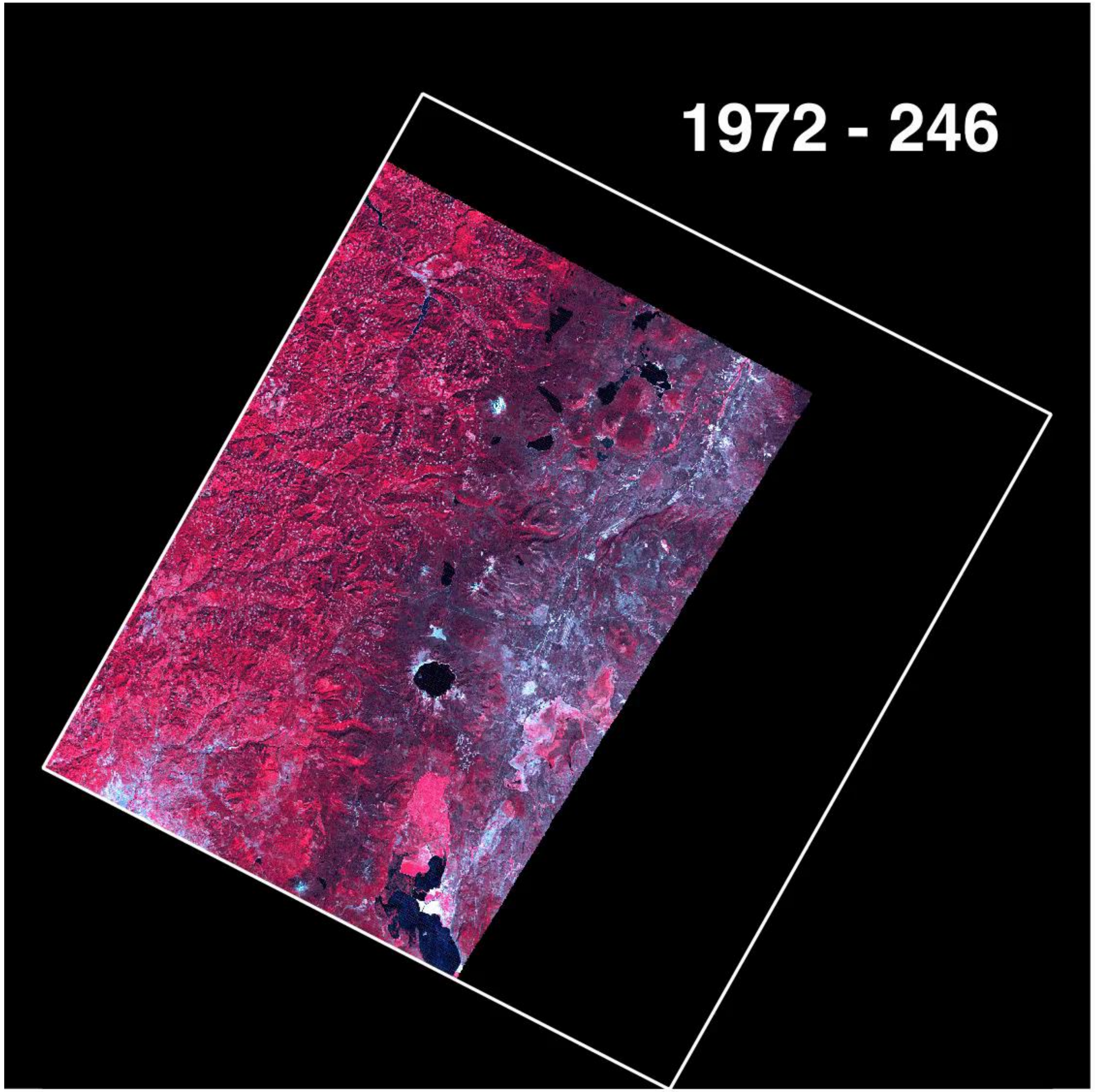
MSS→TM/ETM+ Tasseled Cap B,G,W (RGB) time series

- Small section of 35/32
- Annual data, not composited
- Note dynamic landscape patches against stable background forest mosaic



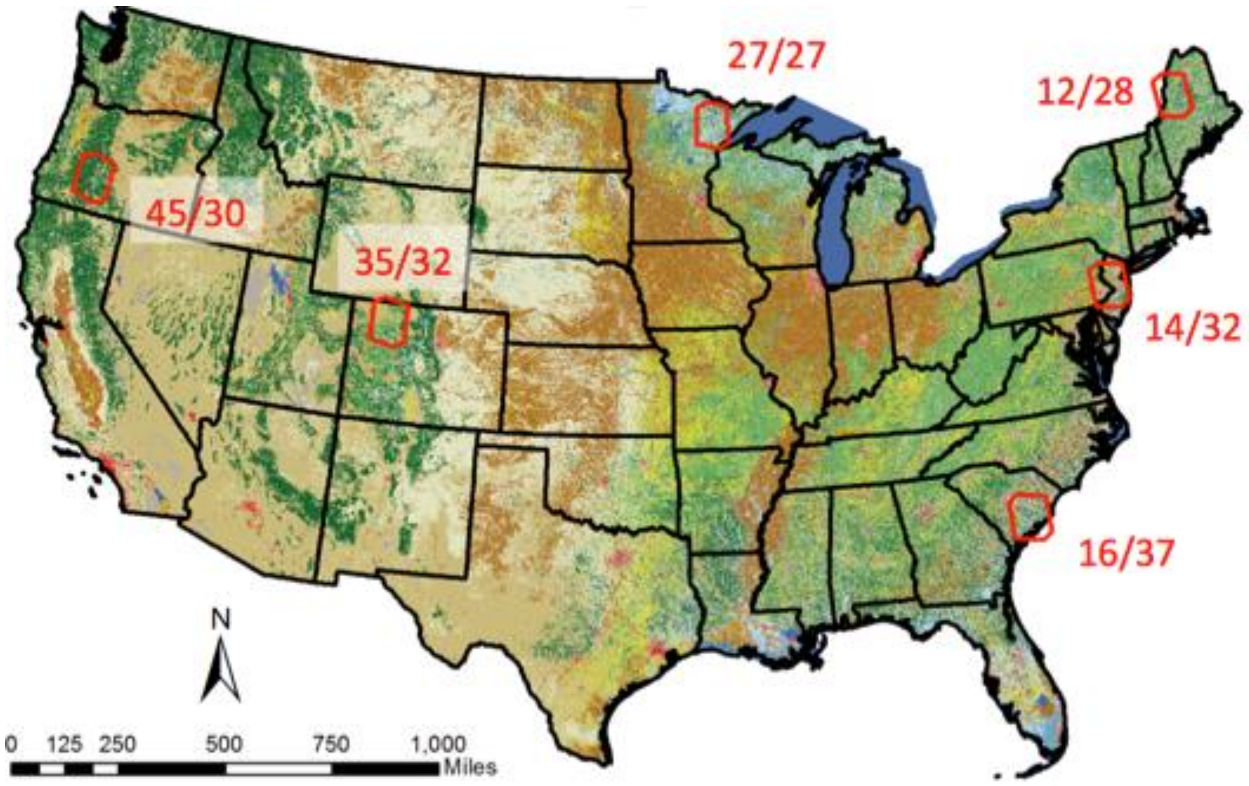
Time Series Movie

- All 45/30 SR images (L1-L3 trimmed to common WRS2)
- TM (4,3,2) NIR, Red, Green (RGB)
- Not cloud screened
- No bias correction



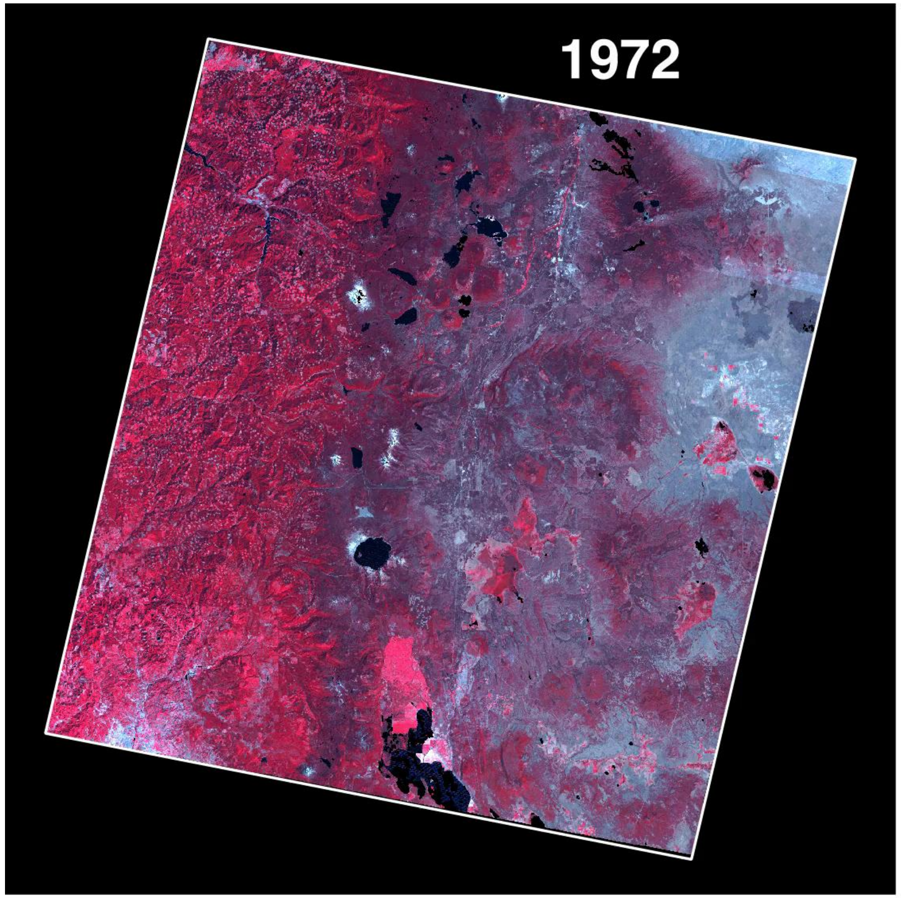
MSS→OLI Harmonized Stacks

- Six scenes being processed (Chavez SR)
  - Almost ready
  - Bands TM/ETM+ 1-5,7
  - Spectral Indices
    - NDVI, NBR, BGW, others
  - All data, not just composites
  - Available to community

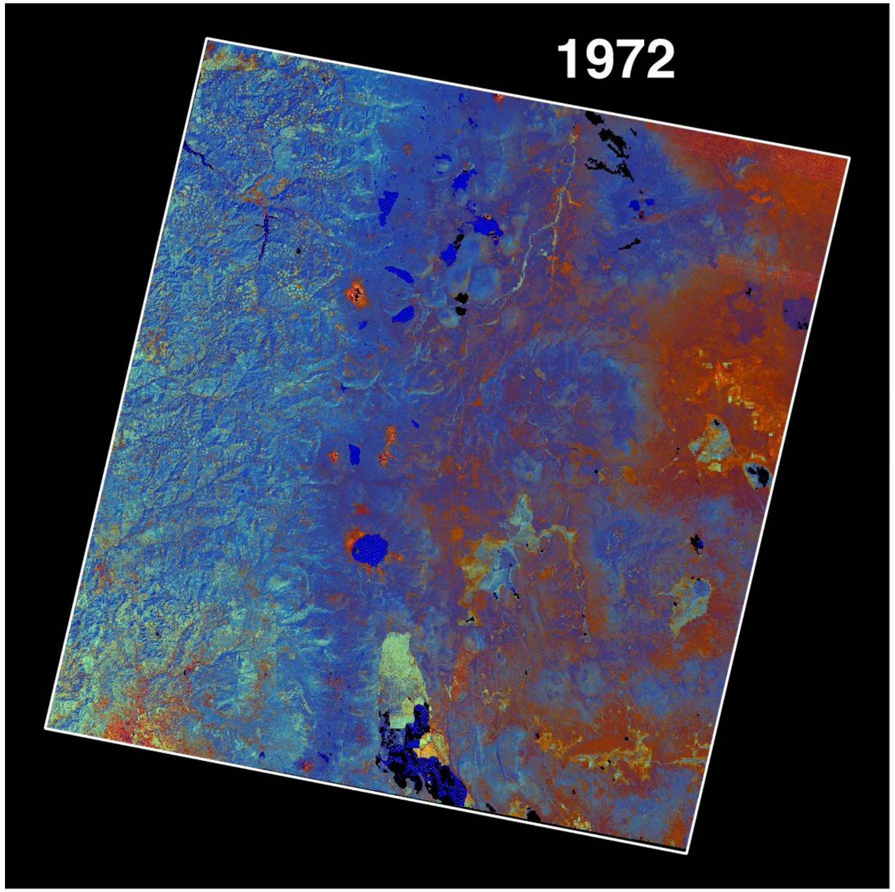


Annual Composites (MSS→OLI) – no bias correction

TM/ETM+ Bands (432)

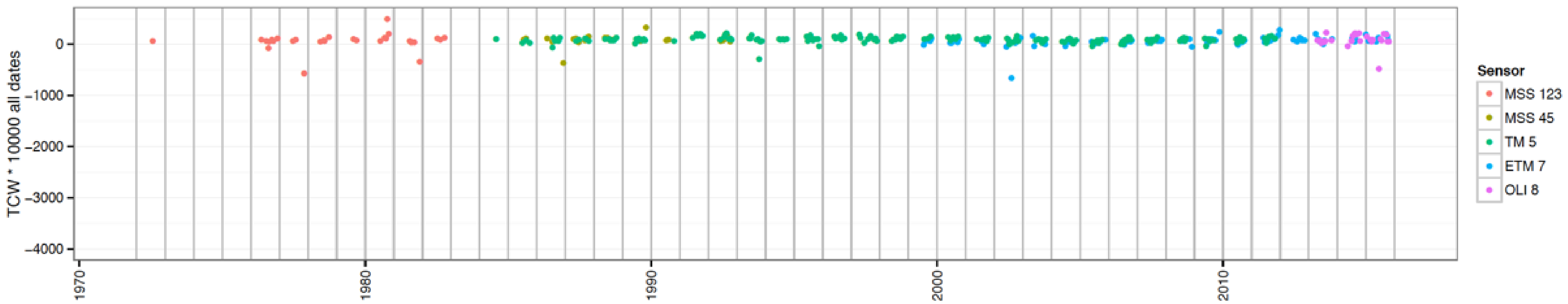


Tasseled Cap (BGW)



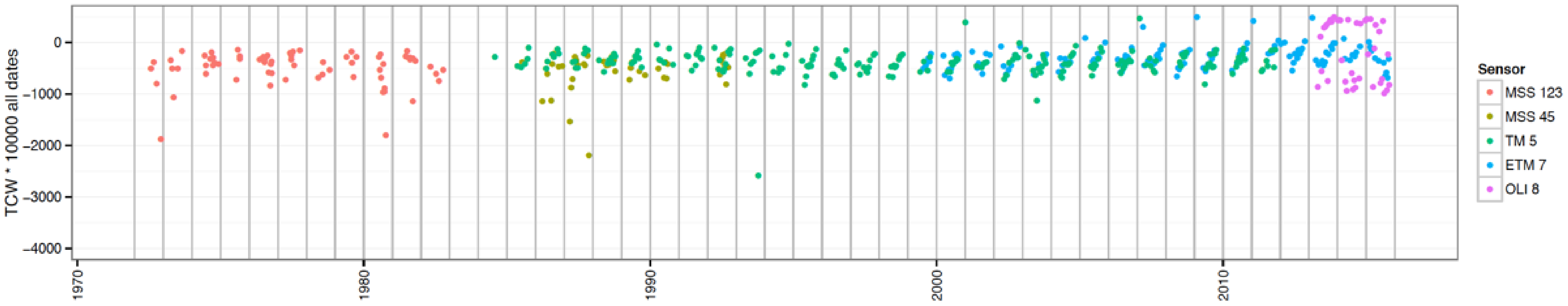
MSS→OLI Pixel Trajectories

- "Stable" features with well behaved trajectories (wetness)



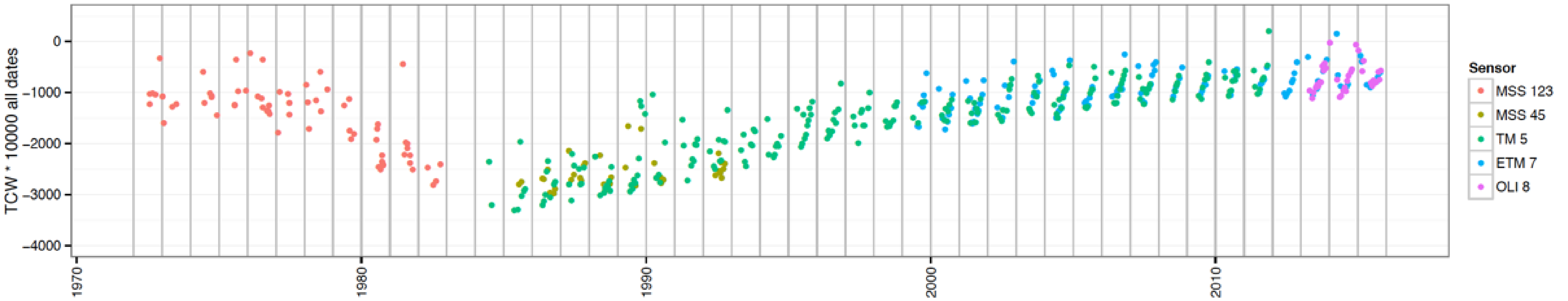
MSS→OLI Pixel Trajectories

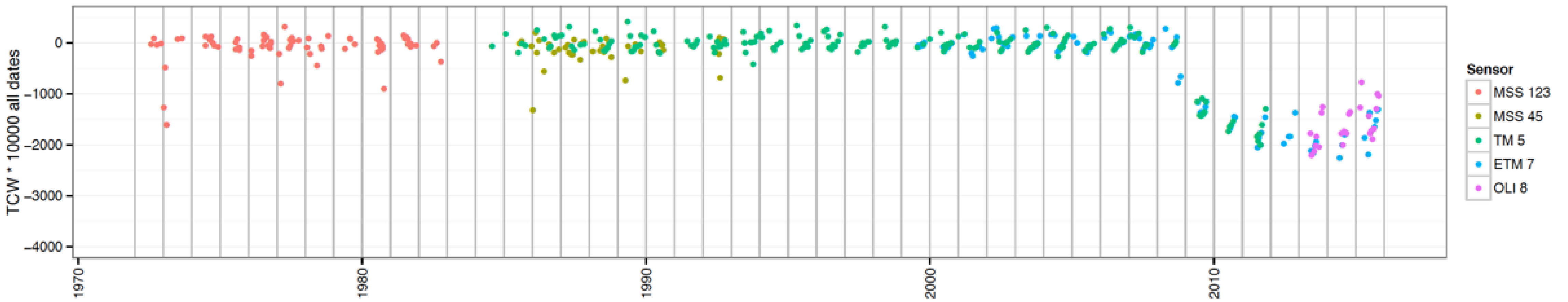
- “Stable” feature with expanded OLI variance (wetness)
  - Cause unknown at this time



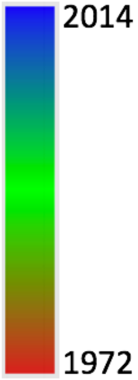
MSS→OLI Pixel Trajectories

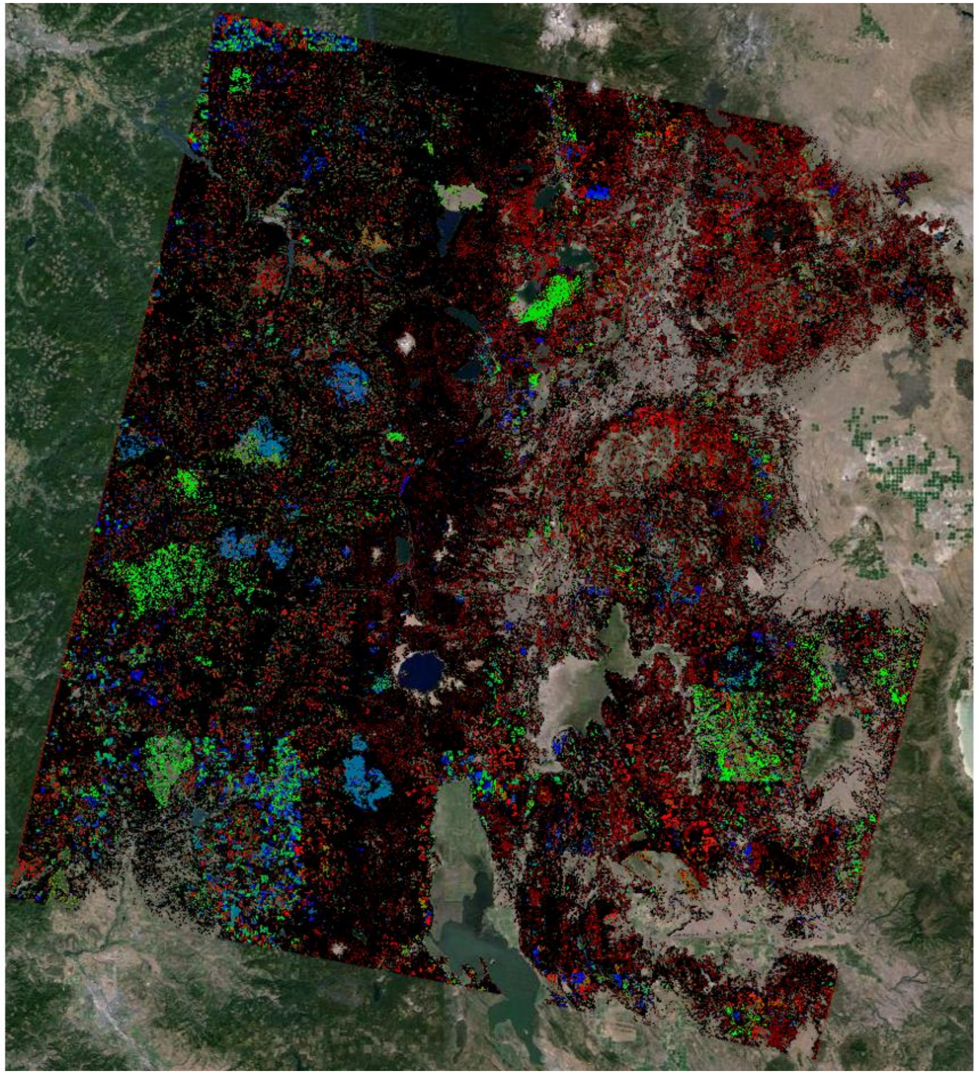
- Changing features (wetness)

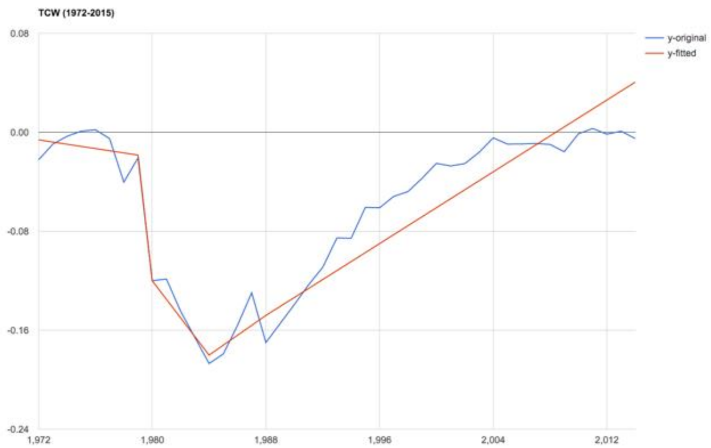


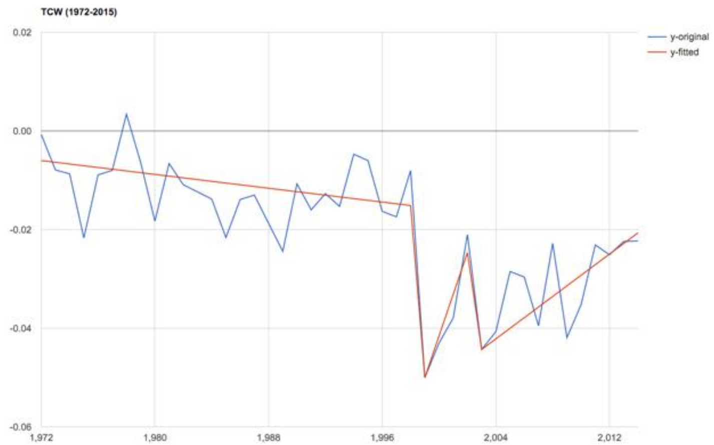


LandTrendr Run on Tasseled Cap Wetness Annual Composites (MSS→OLI)









Analysis Ready Data

- Green, 2006, PE&RS, *Landsat in Context: The Land Remote Sensing Business Model*
  - No other data sets allow us to assess the human condition so effectively...<u>No other data sets can match Landsat's comprehensive record of the Earth and its resources</u>.
- Is it now or never for MSS? Is it time to walk the talk?
- Will USGS finally embrace MSS, giving us improved L1T & SR?
- Or is it time for USGS and the Landsat community to own up to a thus far unstated truth that the broad practical *value of the Landsat program really begins with Landsat 5*, leaving those that need to use the earlier data having to fend for themselves?
- Don't we owe it to W.T. Pecora? Or even more so…don't we owe it to the Earth System?
- Prediction...